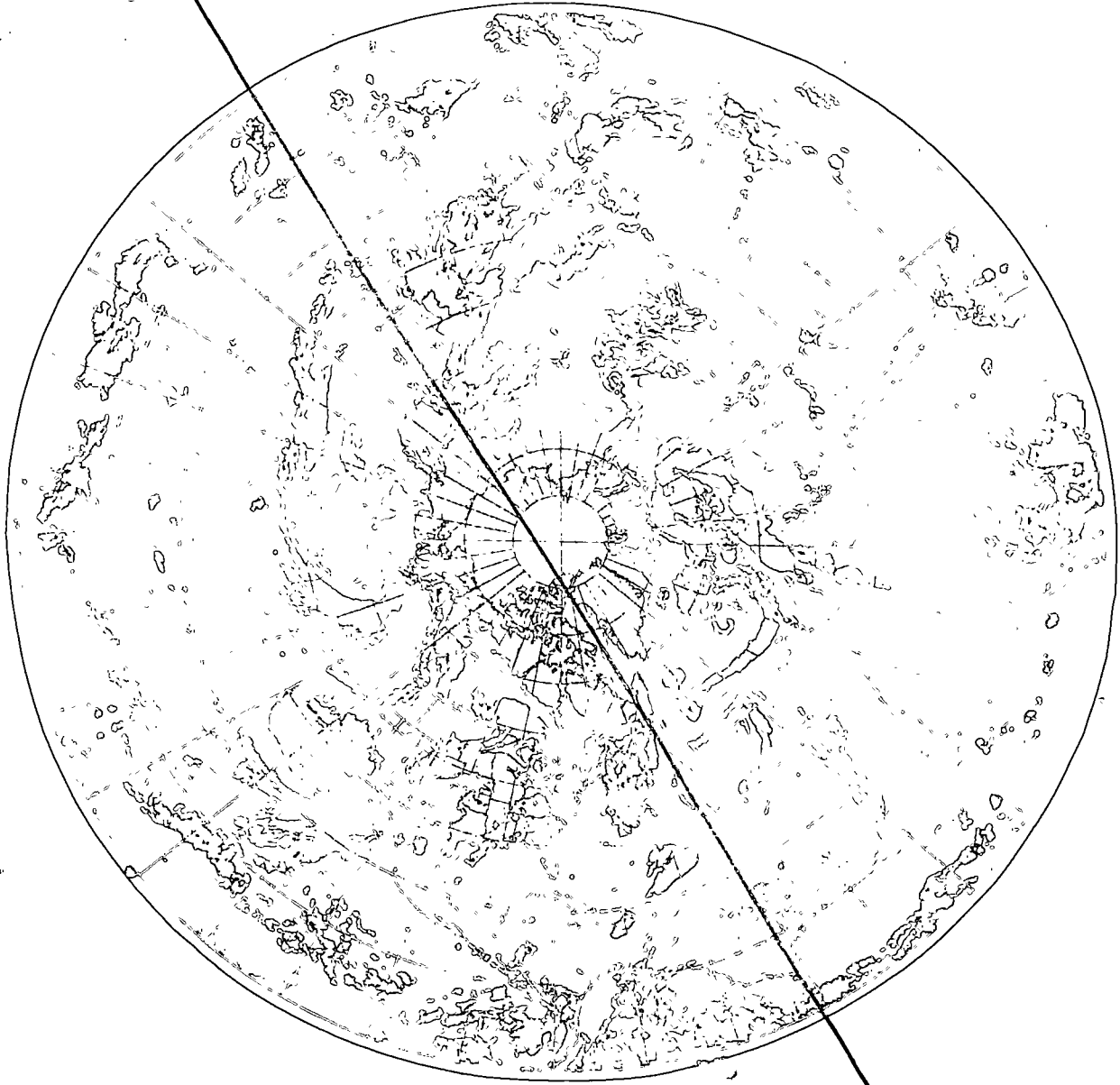


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METEOROLOGY FOR ARMY AVIATORS



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FIELD MANUAL

No. 1-30

HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, D.C., 31 May 1976

METEOROLOGY FOR ARMY AVIATORS

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*This manual supersedes TM 1-300, 10 June 1963, including all changes.



PART ONE

WEATHER PRINCIPLES AND THEORY

CHAPTER 1

INTRODUCTION

1-1. Purpose

This manual provides Army aviation personnel with the general principles of modern meteorology. Its primary purpose is to serve as a text for the Army aviator's study of meteorology and as a continuing reference for day-to-day flight operations. However, it also has application and provides meteorological information that can assist in planning and conducting combat operations.

1-2. Scope

a. This manual covers theoretical aspects of meteorological phenomena, the weather facilities available at airfields, severe weather warnings, types of forecast, and information which will enable Army aviation personnel to interpret and evaluate weather conditions. Although the general information contained in this manual is required background information for weather forecasters, the manual does not include operational forecasting techniques.

b. Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. To insure understanding and complete evaluation, reasons should be provided for each comment. **Comments should be prepared using DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forwarded to the Commander, US Army Aviation Center, ATTN: ATZQ-TD-TL, Fort Rucker, AL 36362.**

c. A list of pertinent references is contained in appendix A.

1-3. General

Army aviators must be knowledgeable of existing weather conditions prior to commencing a flight. To do this, the aviator must have a thorough knowledge of the meteorological conditions and factors which produce the weather along his flight route. Although modern navigational systems and flight techniques make flight into instrument meteorological conditions (IMC) possible, flight into hazardous weather conditions must be avoided. Not only must the aviator be knowledgeable to discern and avoid hazardous weather associated with IMC, he

must also avoid severe turbulence and plan his flight to cope with icing conditions that could exist in cloudless air.

1-4. Meteorology in the High Threat Environment

The effects of weather on the battlefield and adjacent areas can, in many cases, determine the decisions of the commander and significantly influence the outcome of the battle. Army aviation units, as an essential part of the combined arms team, must be able to operate successfully in a number of differing meteorological environments and landscapes affected differently by the weather. The high threat posed by the enemy on the battlefield makes it necessary to conduct combat operational missions in the terrain flight environment close to the earth's surface to avoid detection by electronic means and destruction by highly sophisticated air defense weapons. It is essential that Army aviation units be able to provide firepower, movement of troops, logistical support, and surveillance and reconnaissance for the ground tactical elements even during periods of adverse meteorological conditions. Army aircraft will operate routinely with a minimum of navigational aids and minimum air traffic control facilities. Each aviator must be dependent on individual proficiency and knowledge of meteorological phenomenon to make critical decisions concerning the mission, his crew and passengers, and flight paths. New equipment enabling flight under instrument conditions with minimal navigational aids must be complemented with a thorough understanding of meteorological conditions and the ability to interpret and use it effectively. Army aviators must be knowledgeable of meteorological conditions and factors to be able to make the critical decisions necessary and to operate successfully in the high threat environment.

1-5. Military Weather Support Functions

a. Military meteorological services are specialized services organized worldwide to satisfy unique military requirements. Mobility, responsiveness to combat readiness requirements, and alertness to complement the new weapons systems and concepts are hallmarks of the military weather support

services. General military user requirements include, but are not limited to: meteorological information necessary to support or enhance particular weapons systems being deployed or employed; unique forecasts and analysis for command and control systems; specialized information such as ballistic data, impact prediction, meteorological advisory, and test analysis assistance to research and development; and general meteorological support and information for training and deployment of military forces. These services are provided by forecasting and observation facilities, aerial reconnaissance, meteorological satellites, air-transportable units capable of deploying meteorological support equipment and personnel to support tactical operations, and a global communications network.

b. Atmospheric processes have a significant impact on Army operations. For this reason, the Army is continually developing and improving techniques and equipment that will provide near real-time meteorological information as related to weapons systems. Since Army operations are principally affected by local weather phenomena because of the relatively small area over which they are concentrated, Army meteorologists are concerned primarily with the detailed weather information in the lower atmosphere directly over the battlefield area.

(1) Operational environment services for weather conditions over the immediate battlefield area are provided by a combination of both the Army and the Air Force environmental service units. However, operational weather forecasting is provided to the

Army by the Air Force Air Weather Service. Army meteorological sections provide data, which is assimilated with other environmental data, in order for the Air Force to make accurate weather forecasts.

(2) Specific meteorological support provided by Army weather units include such operations as:

(a) Meteorological observations and soundings in the support of artillery weapons systems.

(b) Meteorological observations forward of division headquarters elements except at some designated airfields.

(c) Specialized meteorological support to Army research and development activities.

(d) River-stage and flood forecasting.

(3) To support artillery weapons systems, there is one meteorological section located in each division, and two additional sections at each corps level. These sections are capable of generating the following five types of meteorological messages:

- NATO ballistic meteorological message.
- Computer ballistic meteorological message.
- Fallout meteorological message.
- Sound-ranging meteorological message.
- Meteorological message for the Air Weather Service.

(4) The ballistic messages allow artillerymen to make corrections for wind, temperature, and atmospheric density—any of which can cause a projectile to miss its intended target. The fallout message allows the corps chemical officer to plot the areas of nuclear fallout, while the sound-ranging message allows enemy weapons to be located by the sound of their firing.

CHAPTER 2 THE ATMOSPHERE

Section I. GENERAL

2-1. General

a. The atmosphere is the great envelope of air which surrounds the earth. Approximately one-half of the air, by weight, is within the lower 18,000 feet of the atmosphere; the remainder is spread out over a vertical distance in excess of 1,000 miles. No definite outer atmospheric boundary exists; the air particles become less numerous with increasing altitude until they gradually overcome the earth's gravitational force and escape into space. The atmosphere rotates with the earth in space as a gaseous outer cover on the terrestrial ball.

b. Within the atmosphere, another type of air movement occurs in addition to the rotation of the air with the earth. Differences in the temperature of the earth's surface affect the density of the atmosphere and cause a continuous internal air movement called *circulation*.

c. The standard atmosphere covered in this FM is in agreement with the accepted United States standard.

2-2. Composition

a. *Gases.* A given volume of dry air contains approximately 78 percent nitrogen; 21 percent oxygen; and 1 percent argon, carbon dioxide, and minute amounts of other gases (fig 2-1). Natural air contains, in addition to the gases present in dry air, a variable amount of water vapor (gaseous water), most of which is concentrated below 30,000 feet. The maximum amount of water vapor the air can hold depends primarily on the temperature of the air; the higher the temperature, the more vapor it can hold.

b. *Impurities.* Air contains variable amounts of impurities such as dust, salt particles, and products of combustion. These impurities are important because of their effect on visibility and especially because they act as nuclei for condensation to water droplets or sublimation to ice crystals. If the air was completely devoid of these impurities, there would be little condensation or sublimation.

2-3. Structure

a. *Weight.* Although extremely light and elastic, air has weight. Because of its weight the atmosphere, under standard conditions, exerts a pressure of

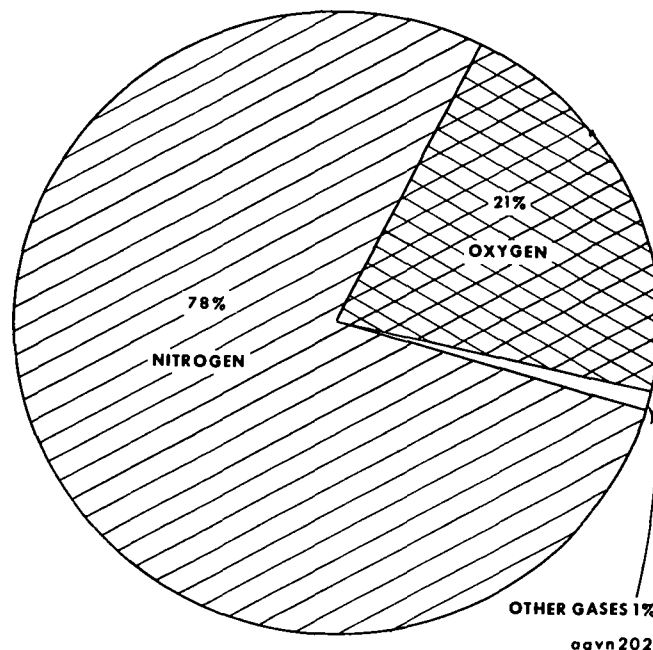


Figure 2-1. Composition of the atmosphere.

approximately 14.7 pounds per square inch at sea level.

b. *Layers.* Figure 2-2 illustrates the division of the atmosphere into concentric layers. The troposphere is the layer closest to the earth. Most of our weather occurs in this layer. Next are the stratosphere, ionosphere, and exosphere. The troposphere varies in height from an average of 60,000 feet above sea level over the Equator to 25,000 feet over the poles. Its height also varies with seasons; it is higher in summer than in winter. In the Temperate Zones during the spring and fall seasons, it is about 35,000 feet above sea level. The boundary zone between the troposphere and the stratosphere is known as the tropopause. The jet stream is generally located near the tropopause.

c. *Weather Elements.*

(1) Weather may be defined as the state of the meteorological elements in the atmosphere. The six major meteorological elements that interact in various combinations to produce weather are *air temperature, humidity, clouds, precipitation, atmos-*

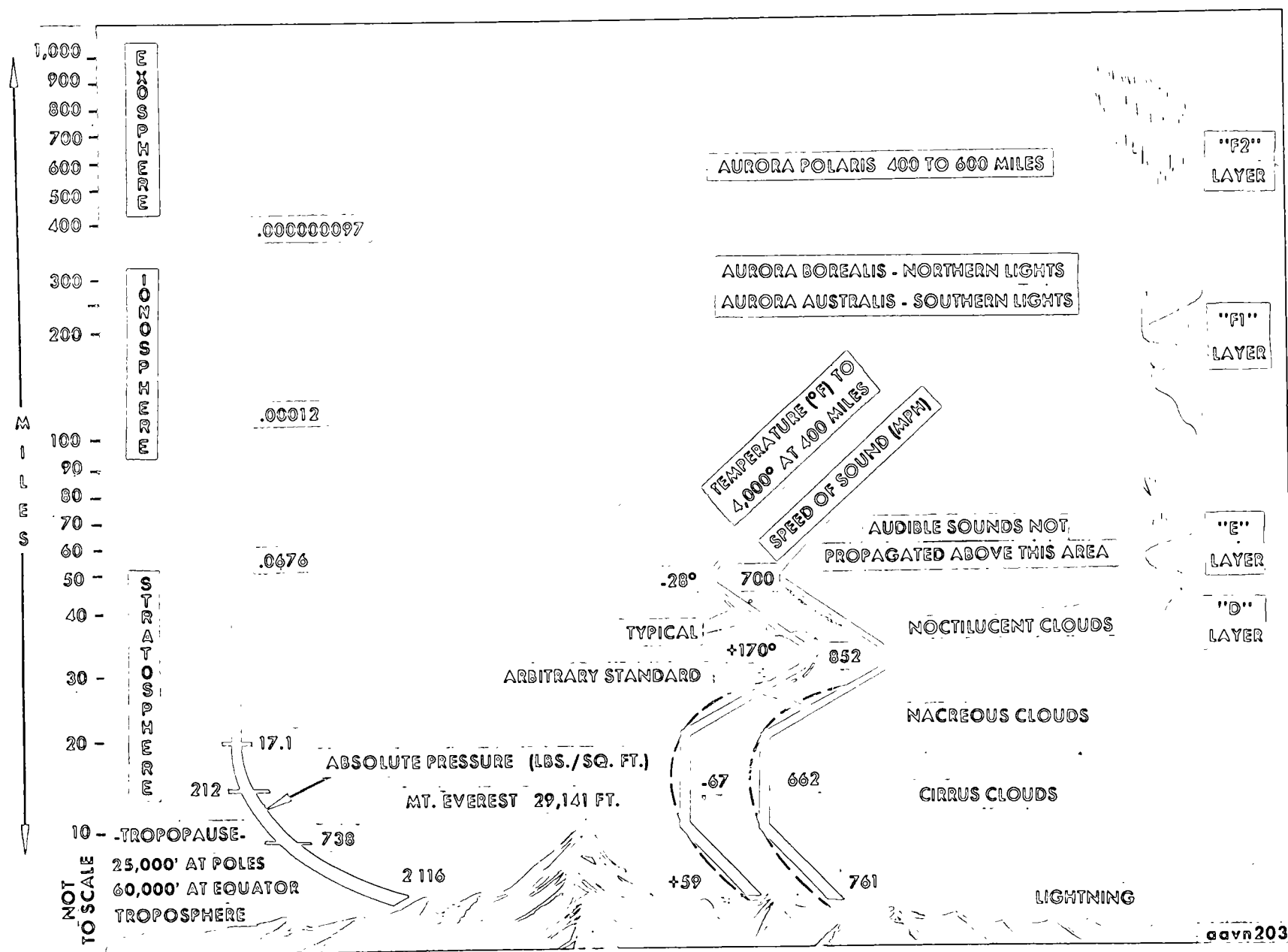


Figure 2-2. The earth's atmosphere.

spheric pressure, and wind. Normally, only air temperature, atmospheric pressure, and wind will be found above the troposphere. The remaining elements (humidity, clouds, and precipitation) are restricted to the troposphere because they require the presence of some form of water—either as a vapor, a liquid,

a solid, or as combinations of these.

(2) Since the main weather hazards to flight (icing, hail, low visibility, low ceilings, and most turbulence) exist only where moisture is available, these conditions are primarily associated with processes occurring in the troposphere.

Section II. TEMPERATURE AND HEAT ENERGY

2-4. Temperature Measurement

According to the molecular theory of matter, all substances are composed of minute molecules which are in more or less rapid motion. Temperature is a measure of the average velocity of the molecules; as the velocity of molecular motion increases in a substance under constant pressure, the temperature of the substance increases. Temperature changes affected by pressure changes are discussed in chapter 5.

a. Measurement. Surface air temperatures are usually measured with liquid-in-glass thermometers. For remote sites and upper air measurements, special temperature sensing devices are used.

b. Scales. Two fixed temperatures—the melting point of ice and the boiling point of water (at standard pressure)—are used to calibrate thermometers. The two scales in common use are centigrade (or Celsius) and Fahrenheit. The centigrade scale was devised by Anders Celsius during the 18th century. The terms “centigrade scale” and “degrees centigrade” have been used for many years; however, the accepted terminology now is “Celsius scale” and “degrees Celsius.” The relationship of the fixed points on each scale is shown on figure 2-3. Army aviators occasionally find it necessary to convert temperature readings from one scale to another because surface temperatures are given in the Fahrenheit scale and Army aircraft are equipped with centigrade thermometers. To convert from Celsius to Fahrenheit, use the equation: $F = 9/5^{\circ}C. + 32$; another equation of the relationship is: $F = 9/5 (^{\circ}C. + 40) - 40$. To convert from Fahrenheit to Celsius, use the equation: $C = 5/9 (^{\circ}F. - 32)$; another equation of the relationship is $C = 5/9 (^{\circ}F. + 40) - 40$.

2-5. Temperature Variation With Altitude

a. There will normally be an overall decrease of temperature in the troposphere as an aircraft gains altitude because the air nearest the earth (which has been heated by incoming solar radiation) receives the largest amount of heat. The variation in temperature with altitude is called the temperature *lapse rate* and is usually expressed in degrees per thousand feet. On one day, the air may have a

C°	F°	C°	F°	C°	F°	C°	F°	C°	F°	C°	F°	C°	F°
-40	-40.0	-27	-16.6	-14	6.8	-1	30.2	12	53.6	25	77.0	38	100.4
-39	-38.2	-26	-14.8	-13	8.6	0	32.0	13	55.4	26	78.8	39	102.2
-38	-36.4	-25	-13.0	-12	10.4	1	33.8	14	57.2	27	80.6	40	104.0
-37	-34.6	-24	-11.2	-11	12.2	2	35.6	15	59.0	28	82.4	41	105.8
-36	-32.8	-23	-9.4	-10	14.0	3	37.4	16	60.8	29	84.2	42	107.6
-35	-31.0	-22	-7.6	-9	15.8	4	39.2	17	62.6	30	86.0	43	109.4
-34	-29.2	-21	-5.8	-8	17.6	5	41.0	18	64.4	31	87.8	44	111.2
-33	-27.4	-20	-4.0	-7	19.4	6	42.8	19	66.2	32	89.6	45	113.0
-32	-25.6	-19	-2.0	-6	21.2	7	44.6	20	68.0	33	91.4	46	114.8
-31	-23.8	-18	-0.4	-5	23.0	8	46.4	21	69.8	34	93.2	47	116.6
-30	-22.0	-17	1.4	-4	24.8	9	48.2	22	71.6	35	95.0	48	118.4
-29	-20.2	-16	3.2	-3	26.6	10	50.0	23	73.4	36	96.8	49	120.2
-28	-18.4	-15	5.0	-2	28.4	11	51.8	24	75.2	37	98.6	50	122.0

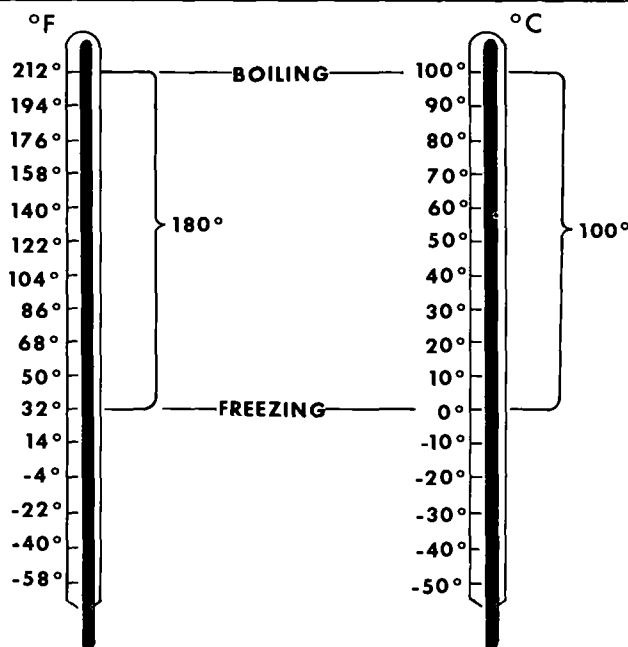


Figure 2-3. Temperature scale.

decrease in temperature of $3^{\circ}C.$ for each thousand feet gained in altitude. Another day may show a decrease of $1^{\circ}C.$ per thousand feet. A third day may reveal the temperature increasing for a distance of one or two thousand feet above the ground (an example of an inverted lapse rate or *inversion*), and thereafter decreasing at the rate of $3^{\circ}C.$ per thousand feet. If such observations taken day after day over thousands of locations on the earth were averaged, the average lapse rate would be about a $2^{\circ}C.$ decrease per thousand feet.

b. Variation of the lapse rate is the main reason that temperatures aloft are normally measured twice daily. Valuable information can be determined from observations aloft, such as—

- Levels at which freezing temperatures (possible icing hazards) occur.
- Types of clouds that will form.
- Maximum and minimum surface temperatures for the day.
- Degree of turbulence in the air (important to flight).

c. Rate of change varies from day to day depending upon the amount of heat reaching the earth, the amount escaping from the earth, and the type and amount of *advection* (warmer or colder air moving into the area from other regions).

2-6. Temperature Inversions

When the temperature increases with altitude within a layer in the atmosphere, this layer is called an *inversion* (inverted lapse rate). Inversions vary in thickness from a few feet to several thousand feet and may occur in a layer of the troposphere at any altitude from the surface to the stratosphere. Inversions occur frequently, but are generally restricted to relatively small layers in the atmosphere. Normal and inverted temperature/altitude relationships are represented graphically in figures 2-4 and 2-5. Inversions near the earth's surface may be formed as follows:

a. *Advection of Warm Air Over a Colder Surface.* Wind may move a mass of air from a warm region over a colder surface, such as wind from the warm ocean moving over the colder land area during the winter season. The air will be cooled quickly at the surface by contact with the cold land mass, while the air at and above 1,000 feet will not be affected for several hours. Thus the surface air will be colder than the air aloft, producing an inverted temperature lapse rate (line B, fig 2-4).

b. *Nocturnal Cooling.* A more frequent type of inversion is caused when the earth cools at night under clear skies. During the afternoon hours, the ground is warm and a normal decrease in temperature with altitude generally exists. However, as the sun sets, the ground loses its heat through terrestrial radiation. This reradiation is not absorbed in significant quantities by clear, dry air. As the ground becomes colder, the air immediately above it is cooled by contact (*conduction*); since air is a poor conductor, this cooling does not extend very high. The air near the surface may become cooler by 2400 hours, whereas the temperature of the air at 100 feet may still be as warm as it was during the afternoon hours, thus inverting the typical afternoon lapse rate. As the surface cooling continues, the inversion layer deepens (fig 2-6).

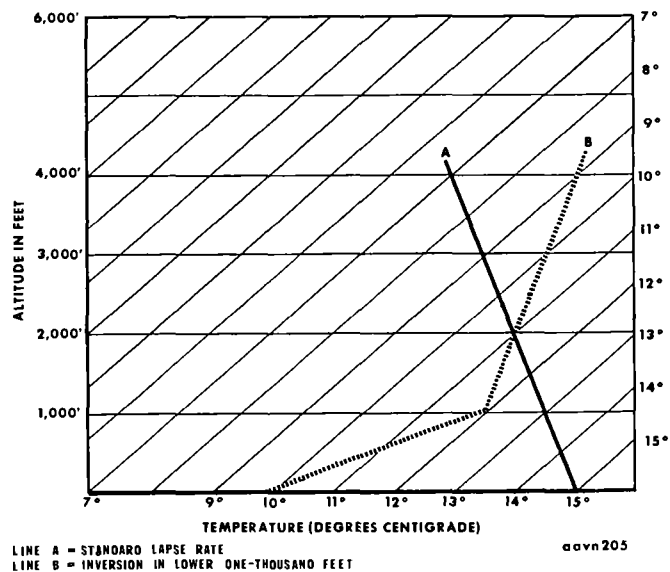


Figure 2-4. Temperature/altitude relationship.

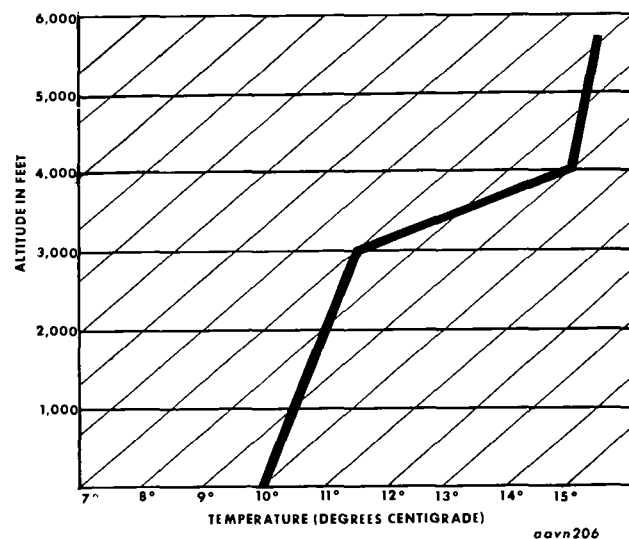
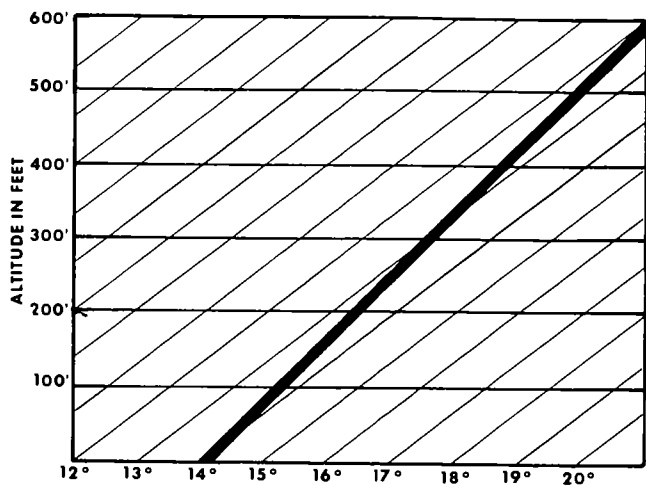


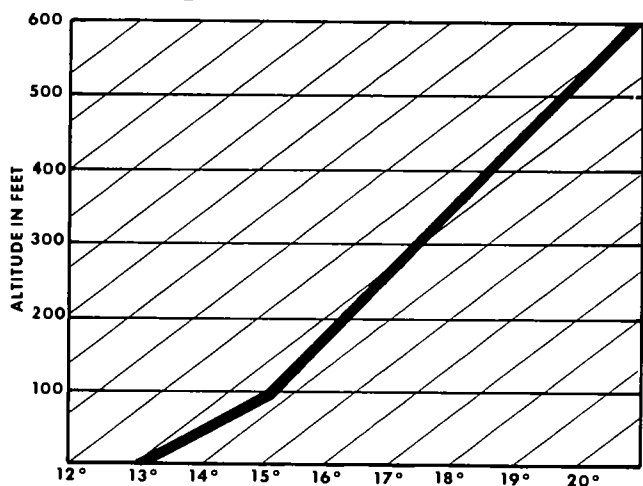
Figure 2-5. An inversion aloft at 3,000 to 4,000 feet.

(1) With relatively strong winds over land, the mechanical turbulence from air moving over the rough surface may thoroughly mix the warm and cool air near the surface so that no well-defined inversion exists near the ground, although an inversion may exist several hundred feet above the ground (fig 2-5 and 2-7).

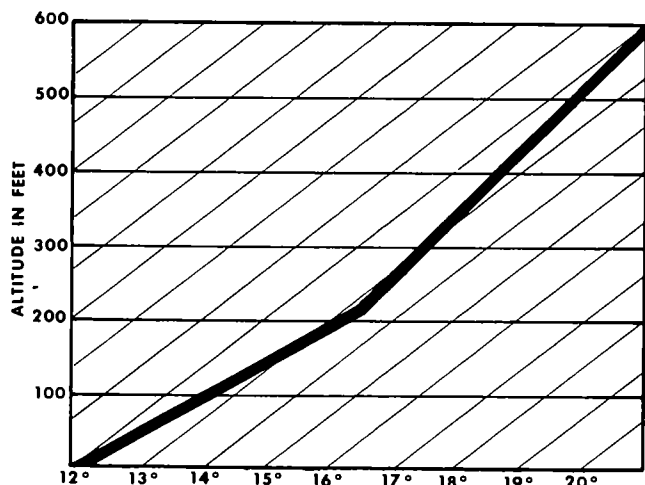
(2) Inversion layers are stable and produce smooth flying conditions within them; however, fog, haze, smoke, and dust below and within inversion layers often restrict visibility. If skies are overcast, nocturnal cooling is reduced (greenhouse effect, para 2-10a(3)), and it is unlikely that a nocturnal inversion will form.



TEMPERATURE (DEGREES CENTIGRADE)
 (A) 1800 LOCAL STANDARD TIME

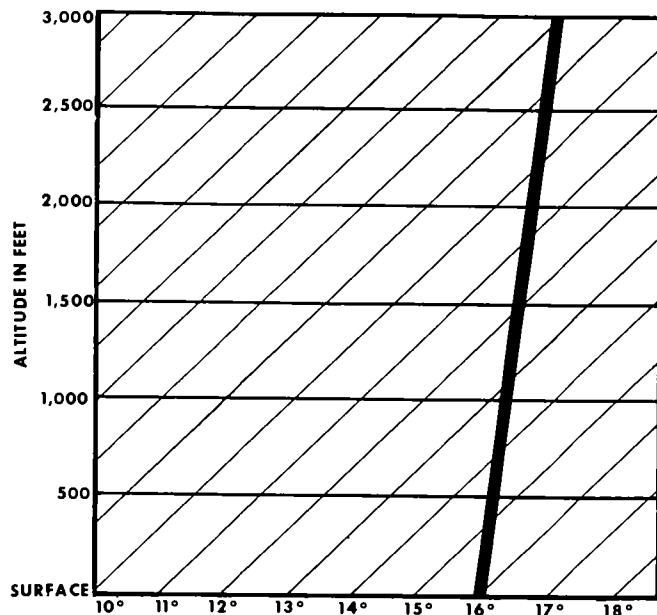


TEMPERATURE (DEGREES CENTIGRADE)
 (B) 2400 LOCAL STANDARD TIME

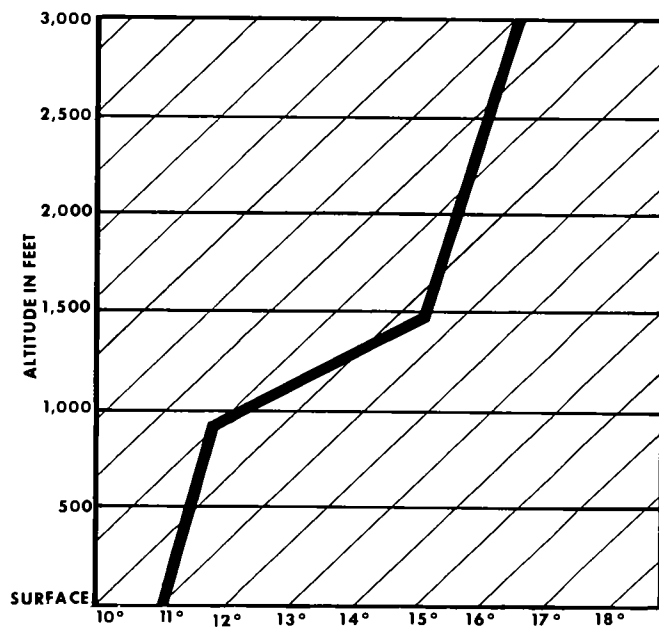


TEMPERATURE (DEGREES CENTIGRADE)
 (C) 0600 LOCAL STANDARD TIME aavn207

Figure 2-6. A nocturnal inversion.



TEMPERATURE (DEGREES CENTIGRADE)
 (A) 1800 LOCAL STANDARD TIME (LST)



TEMPERATURE (DEGREES CENTIGRADE)
 (B) 0600 LOCAL STANDARD TIME (LST).

aavn208

Figure 2-7. A nocturnal inversion with moderately strong surface wind.

Note. Inversions aloft are also caused by frontal activity (para 7-2a), by subsidence in areas of high pressure (para 4-9d), and by warm air advection aloft (para 14-5b).

2-7. Free Air Temperature

Temperatures used in aviation meteorology are those of the free air. Free air temperature measuring instruments are housed so that they are not in direct contact with sunlight. This housing also minimizes other effects which might cause inaccuracies in the readings.

Note. Measurement of outside air temperatures with standard aircraft thermometers is influenced by several factors (radiation, air pressure, and friction) which tend to decrease the accuracy of the indicated temperature. These factors may cause the reading to differ from the true free air temperature by more than 5° F.

2-8. Temperature Variation On the Earth's Surface

Three important factors responsible for temperature variation on the earth's surface are the earth's *daily rotation about its axis*, *yearly revolution around the sun*, and *variations in land mass and water mass heating*.

a. Daily Rotation. Daily surface heating and cooling results from the earth's rotation about its axis (fig 2-8). As the earth turns, the side facing the sun is heated and the side away from the sun is cooled. Generally the lowest temperature occurs near sunrise, and the highest temperature is between 1300 and 1500 hours.

b. Yearly Revolution. The effects of the yearly revolution around the sun are modified by the tilt in



Figure 2-8. Daily heating and cooling of the earth's surface.

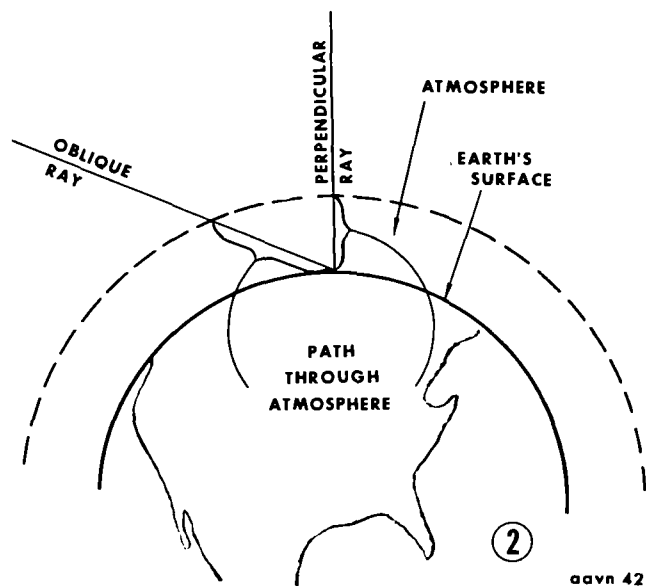
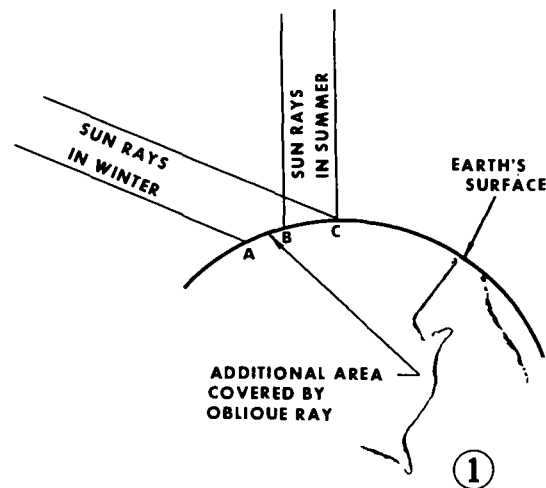


Figure 2-9. Variations in solar energy received by the earth.

the axis of the earth. Areas under the direct or perpendicular rays of the sun receive more heat than those under the oblique rays. One factor affecting this is shown in part 1 of figure 2-9. Let the lines intersecting the ground represent a group of rays from the sun which in turn represents a given amount of energy. As these rays strike the ground obliquely, as in winter, the energy is distributed over an area whose width is from A to C. In summer, with the sun closer to the overhead position, the same group of rays fall on an area whose width is from B to C which is much less than A to C. Thus, the sun's energy is more concentrated in summer than in winter which results in greater heating per unit area. Another reason for the lesser heating in winter is that the oblique rays pass through more of the atmosphere which absorbs, reflects, and scatters the sun's energy. Fewer of these oblique rays reach the earth's surface or lower layers of the atmosphere, (part 2, fig 2-9).

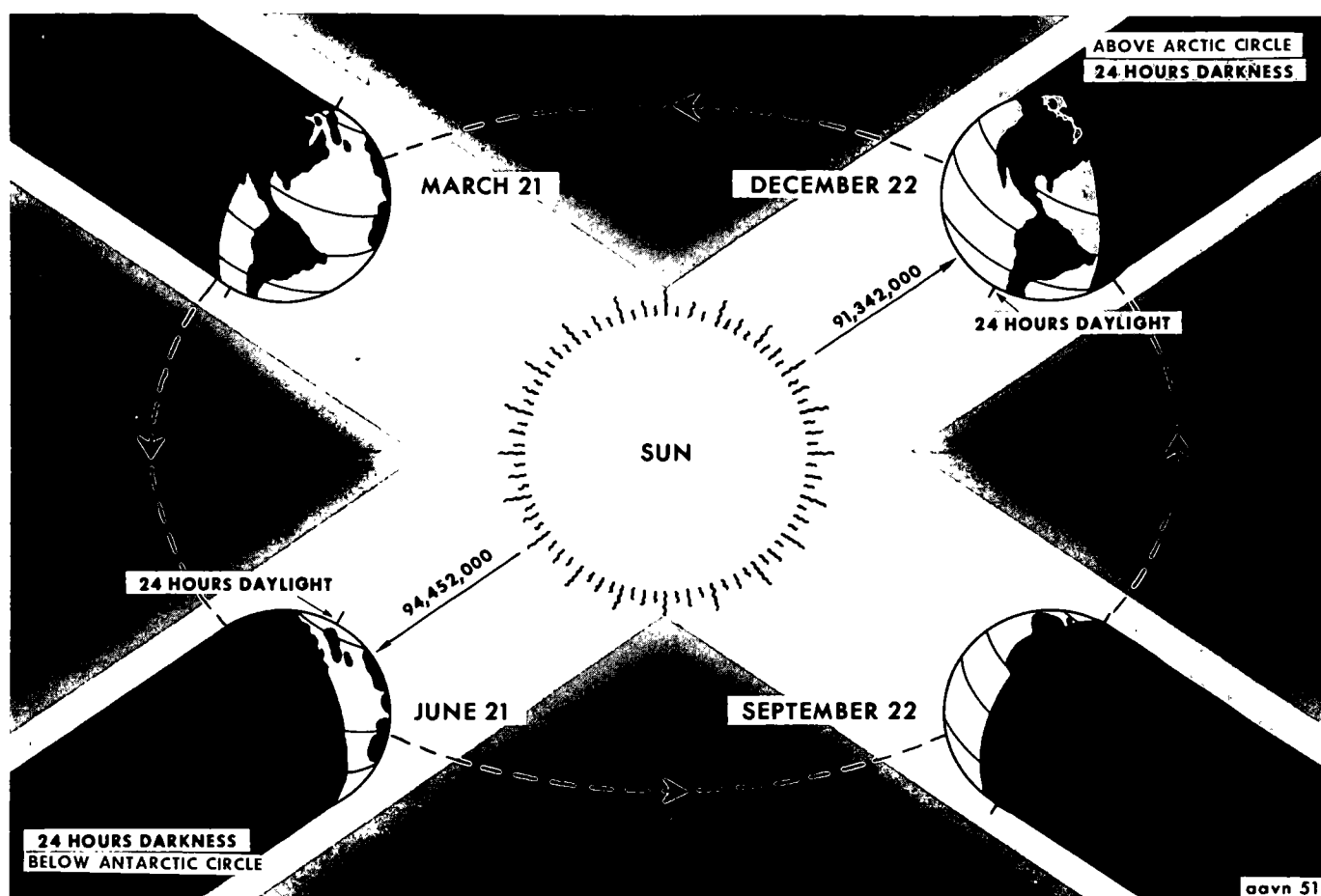


Figure 2-10. Effect of inclination of the earth on seasons.

(1) Each year the perpendicular rays of the sun migrate from $23\frac{1}{2}^{\circ}$ north latitude (June 21) to $23\frac{1}{2}^{\circ}$ south latitude (December 22), causing the seasons of the Northern and Southern Hemispheres. The warmest weather of the Northern Hemisphere comes 30 to 40 days after June 21 (see also *temperature lag*, glossary), when the most heat has been absorbed from the sun. This is the cold season in the Southern Hemisphere.

(2) The migration of the perpendicular rays of the sun results from the revolution of the earth around the sun while the earth's axis is tilted $23\frac{1}{2}^{\circ}$ and remains parallel to its previous positions (fig 2-10). The perpendicular rays of the sun strike the earth's surface at $23\frac{1}{2}^{\circ}$ north latitude on June 21, at the Equator on September 22, at $23\frac{1}{2}^{\circ}$ south latitude on December 22, and at the Equator again on March 21.

(3) Unequal duration of daylight contributes to the uneven distribution of heat. Each pole has 6 months of daylight and 6 months of night each year (fig 2-10). On June 21, all territory within the Arctic Circle has 24 hours of daylight; on December 22, all territory within the Arctic Circle has 24 hours of darkness or twilight. For any given latitude, long

days produce maximum heating and long nights produce maximum cooling.

c. Variations in Land Mass and Water Mass Heating. Land areas heat and cool more rapidly than water areas; water tends to have a more uniform temperature throughout the year. During the night, water retains its warmth while the land mass rapidly loses its heat to space. This difference between land and water heating rates also influences seasonal temperatures. In winter, oceanic climates are warmer than continental climates at the same latitude; in summer, the oceanic climates are cooler. Seattle, Washington, for example, has far warmer winters and somewhat cooler summers than Fargo, North Dakota, which is at the same latitude but farther inland.

(1) Water surfaces heat more slowly than land surfaces for the following reasons:

(a) In early morning and late afternoon, water surfaces reflect more solar radiation than land surfaces reflect.

(b) Sun's rays penetrate 30 feet or deeper into water surfaces, but may affect only 4 inches of land surface.

(c) Ocean currents and turbulence within the

water distribute the absorbed solar energy over large areas.

(d) The specific heat of water is approximately four times that of land; that is, four times as much heat is required to raise the temperature of a given mass of water one degree as is required to raise the temperature of an equal mass of land one degree. Different specific heats result from variations in the molecular structure of the two substances.

(e) Evaporation, which occurs over water surfaces, lessens the heat gained by solar radiation.

(2) Water retains its temperature longer than land chiefly because it heats to greater depths. Only the top few inches of a land surface radiate heat during the night. However, as water at the surface cools, it sinks and is replaced by warmer water from below. This movement of the water keeps the surface warm throughout the night.

2-9. Local Heat Distribution

Local surface temperature variations may be caused by cloudiness or by the nature of a particular surface.

a. Clouds are excellent reflectors of solar radiation; also they are a factor in the retention of terrestrial radiation (fig 2-11).

b. The earth's color, texture, and vegetation coverage influence the rate of heating and cooling. Generally, dry surfaces heat and cool faster than moist surfaces. Plowed fields, sandy beaches, and paved roads become hotter than surrounding meadows and wooded areas. During the day, air is warmer over a plowed field than over a forest or swamp; during the night, the heat distribution is reversed.

2-10. Methods of Heat Transfer

When a solid object or a given volume of liquid or gas loses more heat energy than it gains, its temperature decreases; when it acquires more heat energy than it loses; its temperature increases. At times, a complete change in the character of the weather occurs over land areas between early morning and midafternoon. This change takes place as a result of the heating and cooling of the earth and its atmosphere. The four effective methods of heat transfer in the heating and cooling of the earth and its atmosphere are *radiation*, *conduction*, *convection*, and *advection*. (See also *cooling processes*, *major*, glossary.)

a. *Radiation (Solar and Earth)*. Radiation is the process by which energy is transferred through space or through a material medium from one location to another in the form of electromagnetic waves. The high-frequency energy radiated by the sun is the primary source of heat energy on the earth. As energy passes through the atmosphere, about 42 percent is reflected back to space, about 15 percent is absorbed near the earth's surface, and about 43 percent reaches the surface. The 15 percent absorbed by the atmos-

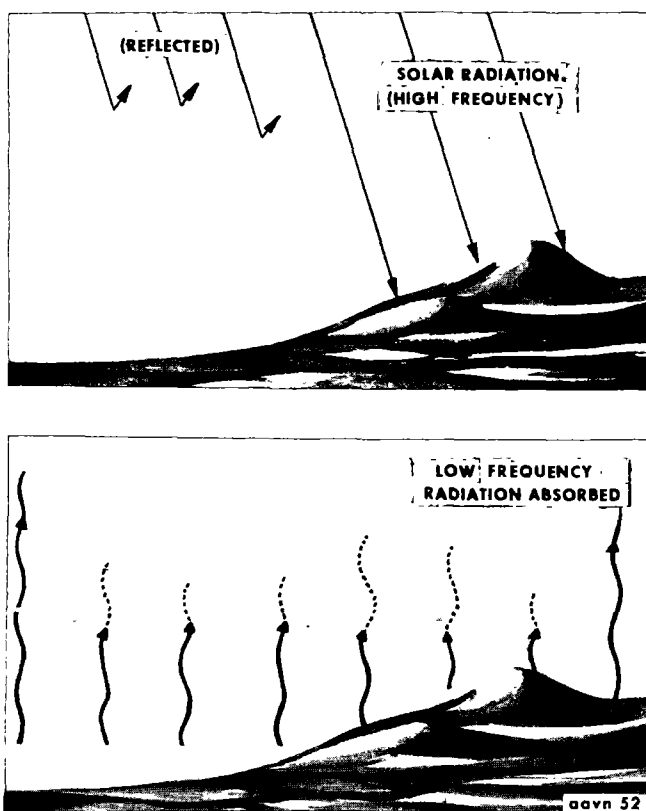


Figure 2-11. Reflection and absorption of radiation by clouds.

phere has only a minor effect on atmospheric temperature. Primarily, the earth receives its heat from the 43 percent that reaches its surface.

(1) *Insolation*. The sun is the sole source of the heat energy that affects weather. Heat energy supplied by the sun is in the form of radiant energy called *insolation* (*incoming solar radiation*), the majority of which is short wave radiation not absorbed by the atmosphere. The earth's surface is heated as it absorbs this radiant energy. The amount of insolation absorbed by the surface of the earth is affected by the—

- Inclination of the plane of the sun's rays to the plane of the horizon.
- Distance of the earth from the sun.
- Duration of daylight.
- Character of the earth's surface.
- Amount and type of clouds and impurities present.

(2) *Terrestrial radiation*. The earth's surface both absorbs and radiates heat energy. The long wave radiation from the earth's surface is known as *terrestrial radiation*. Since low frequency, long wave radiation possesses a low penetration quality, the impurities in the atmosphere absorb a considerable amount of the terrestrial radiation. The reradiation process is fundamental to the heating of the earth's atmosphere. Since terrestrial radiation remains in balance

with insolation radiation, the earth becomes neither incandescent nor frozen.

(3) *Greenhouse effect.* Greenhouse effect refers to the ability of water vapor, smoke, haze, and particularly clouds to reduce or prevent the cooling of the earth during the night. These impurities in dry air readily absorb low-frequency terrestrial radiation and reradiate it to the earth. Thick overcast clouds return practically all of the terrestrial radiation, and the air temperature below them may drop as little as 2° F. during an entire night. These clouds produce an effect on radiation similar to that produced by the glass top on a greenhouse. They allow a large portion of high-frequency insolation to pass through and heat the earth, but they block the passage of low-frequency terrestrial radiation which retains the heat below them. High concentrations of water vapor and smoke cause a partial greenhouse effect and may also noticeably reduce nocturnal cooling.

b. Conduction. Conduction is the transfer of heat by contact. This process is important in meteorology because it causes the air close to the surface of the earth to heat during the day and cool during the night. However, air is a poor conductor (as shown by the use of dead airspace in thermopane glass and by airspace insulation in buildings), therefore only the air temperature at the immediate surface of the earth is affected directly by conduction.

c. Convection. When a parcel or mass of air moves upward or downward in the atmosphere, it carries its own heat energy. This vertical movement of air produces the method of heat transfer known as *convection*, which is classified as *thermal* or *mechanical*.

(1) *Thermal convection.* The surface air, after being heated by conduction and terrestrial radiation, expands in volume and decreases in density. Because of expansion, a portion of the warmer, lighter column of air overflows aloft, thereby decreasing its own pressure at the surface and at the same time increasing the surface pressure of the adjacent cooler air. This causes a lifting of the warmer, lighter air column by the heavier, cooler, settling air which flows in and displaces the warm air at the surface. The warm surface air, expanded and therefore less dense, is like a cork that is held under water; i.e., it is unstable and tends to rise. The rising and descending air of this nature is referred to as *thermal* convection, since the convection is produced by a temperature contrast within the air layer. Strong thermal convective currents occur most frequently during the afternoon when surface heating and temperature contrasts are greatest; i.e., between water and land, plowed fields and grassy areas, swamps and rocky terrain, or in regions where the surface is extremely hot. The vertical movement of the air displaces aircraft flying through it and produces turbulence in varying degrees

of intensity, generally strongest during the hours of maximum surface heating.

(2) *Mechanical convection.* Air passing from one side of a mountain range to the other side is forced into vertical movement by the mechanical lifting from the terrain (*orographic lifting*). Flights over mountainous areas are frequently bumpy and turbulent because of mechanical convection. In areas where clouds are forming on the windward side of a slope, both thermal and mechanical convection often occur. The air is lifted orographically until it becomes warmer than the surrounding air at the same altitude, and then continues to rise by thermal convection. (See also *level of free convection* in paragraph 5-5d.) This action forms large billowy clouds and even thunderstorms when large amounts of water vapor are present.

d. Advection. The horizontal movement of air (wind) is called *advection* (compare with *e* below). Advection, like the other methods of heat transfer, may produce either a heating or cooling effect in a given area. This heating and cooling is most noticeable in the Temperate Zone during the winter months when cold and warm air masses alternately affect a given location, but advection occurs during all seasons.

(1) The movement of colder air into an area is called *cold air advection*. During the winter months, for example, masses of cold air from Canada predominate in Central and Eastern United States. The movement of this cold Canadian air southward is cold air advection. Cold air advection usually produces good flying weather except during the winter on the lee sides of relatively large water bodies such as the Great Lakes.

(2) The movement of warmer air into an area is called *warm air advection*. During the winter months, for example, masses of warm air from the Gulf and Atlantic may affect areas in Southern and Eastern United States. The movement of this warm air northward is warm air advection. The advection of warm moist air over land during the winter is characterized by low overcast clouds and reduced visibility.

e. Advection and Isotherms. An *isotherm* is a line connecting points of equal temperature. The horizontal flow of air across isotherms indicates advection. Wind flowing from the cold air side of the isotherms across to the warm air side is *cold air advection* since cold air is moving into an area previously occupied by warm air. Wind flowing across isotherms from the warm air side to the cold air side is *warm air advection*. Warm air advection at the surface results in the air being *cooled* from below. Cold air advection at the surface results in the air being *heated* from below. This heating and cooling from below is a consideration in the analysis of air mass weather.

Section III. MOISTURE

2-11. Moisture Changes

Most weather hazards that interfere with the operation of aircraft are associated with water in one of its three states—vapor, liquid, or solid. Water vapor is water in the gaseous state and is not visible. When it changes into liquid water droplets, it becomes visible as clouds, fog, dew, rain, or drizzle. Some water droplets, remaining in the liquid state at temperatures well below freezing, change into ice only when disturbed by an outside force, such as an aircraft wing or blade. These water droplets are supercooled and cause structural icing on aircraft. Water in the atmosphere appears in the solid state as frozen water droplets, ice crystals, and snow.

a. Evaporation. Evaporation is a change in state from a liquid to a gas. According to the kinetic theory of matter, the molecules in a liquid are in constant motion with some molecules having a greater velocity than others. Some of the higher energy molecules obtain a velocity great enough to overcome the surface tension of the liquid and escape (evaporate). If the temperature of the liquid is increased, more of the molecules will obtain escape velocity and the rate of evaporation will increase. If the liquid is in a closed container with a space above it, the escaping molecules will cause a slight increase in pressure (vapor, pressure, vapor tension). Evaporation will continue at a decreasing rate until the vapor pressure above the liquid is equal to the pressure in the liquid that caused the molecules to escape. When this balance is reached, evaporation will cease and the space above the liquid will become saturated with water vapor. The vapor pressure atop the liquid is known as saturated vapor pressure. If the top of the container is removed and unsaturated air circulated over the liquid, evaporation will again commence. The rate of evaporation will be proportional to the vapor pressure above the liquid, the temperature of the air, and the temperature of the liquid. The greatest rate of evaporation will occur when warm, dry air is circulated over a warm liquid. During evaporation, the higher energy molecules escape and the overall energy or heat content of the liquid is reduced. This results in a cooling of the liquid, and by conduction, of the environment surrounding the liquid. At a temperature of 100° Celsius, 540 calories of heat energy is lost from the liquid for every gram of water that evaporates. This is known as the latent heat of vaporization.

b. Condensation. Condensation is the change of state from a gas to a liquid. Water vapor at 100° C. contains approximately 540 calories per gram more heat energy than liquid at the same temperature (*a* above). Since energy cannot be destroyed, the formation of water droplets from the vapor must release

this quantity of heat energy to the environment. The process of condensation has a heating effect. In the atmosphere, condensation normally lessens the cooling effects of other processes. The latent heat energy released from the condensation in a single cloud may involve billions of calories. This energy produces the force required to develop the extreme winds and turbulence in thunderstorms, tornadoes, and hurricanes. Impurities must also be present in the atmosphere to act as a nucleus around which fog and cloud droplets can form. Laboratory experiments have shown that if air is free of impurities, it can be cooled well below its normal capacity for maintaining its moisture in vapor state (supersaturation), without condensation or sublimation occurring. It is suspected that this phenomenon also occurs in certain regions of the world's atmosphere where few impurities exist (e.g., high altitudes and polar regions.)

c. Sublimation. The direct change of state from solid to vapor and vice versa, without passing through the intermediate liquid state, is called *sublimation*. This process takes place at temperatures below 0° C. and is similar to evaporation and condensation in that latent heat is liberated when solidification takes place and is absorbed when evaporization occurs. At temperatures below 0° C., ice or snow can sublime directly into the air as water vapor, and when the required nuclei are present, the water vapor can sublime directly into ice crystals. Figure 2-12 illustrates the heat exchanges involved in the process of evaporation, condensation, and sublimation.

d. Heat Exchange. The amount of heat necessary to melt ice at 0° C. (heat of fusion) is 80 calories per gram of ice. As much heat is needed to change ice at 0° C. to water having the same temperature as is needed to heat the resulting water from 0° to 80° C. (fig 2-12). Heat energy is also required to convert liquid water into vapor. At normal atmospheric temperatures, this requirement is about 600 calories per gram (597 calories per gram at 0° C. and 540 at 100° C.). Vapor condensing into water at normal atmospheric temperatures gives off about 600 calories of heat. This heat is called the latent heat of *vaporization* (or latent heat of condensation). For example, in the ordinary steam heating system, the steam produced in the boiler discharges its heat of condensation to the radiator in which it condenses; the heat is radiated from the radiator into the room.

2-12. Water Vapor Content

a. Saturation. Saturation is a condition that exists when air at a given temperature and pressure is holding the maximum possible water vapor content. In the atmosphere, saturation occurs by evaporation into

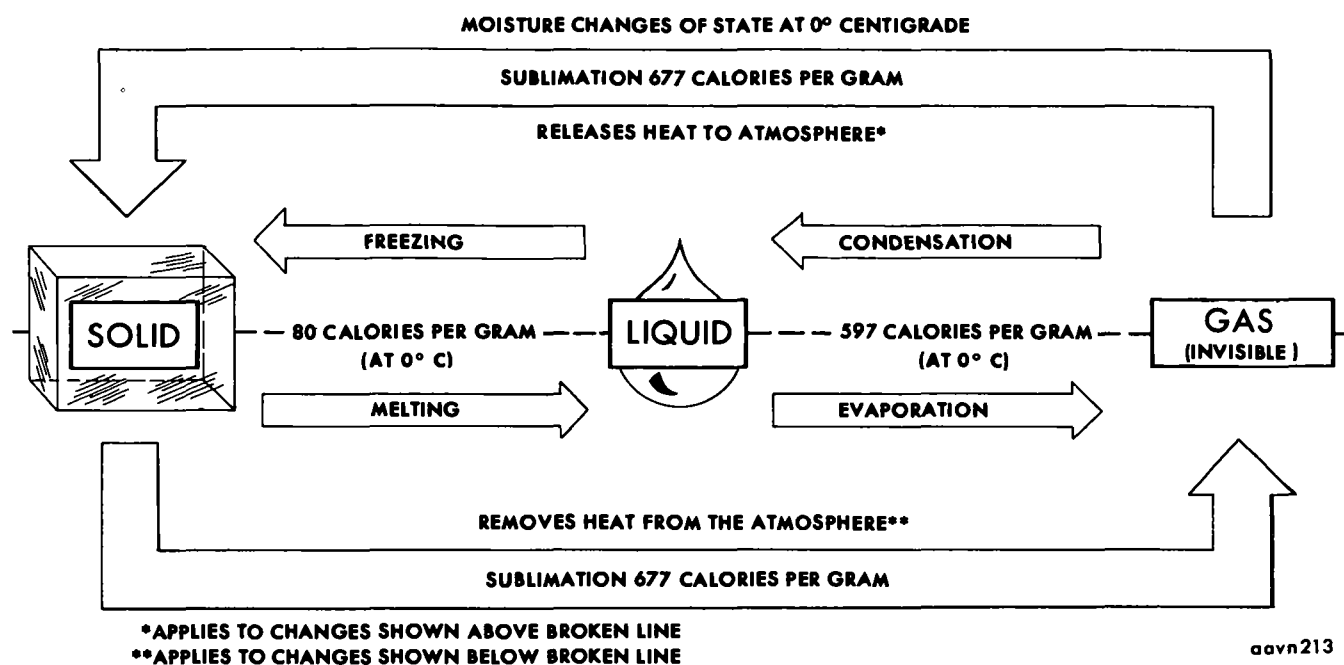


Figure 2-12. Heat exchanges.

the air from a free water surface (ocean, lake, river, rain drops) until vapor pressure equilibrium ((1) below) between the water and the air is reached; or lowering of the air temperature, thereby decreasing the saturation vapor pressure until it is the same as the actual vapor pressure of the water vapor in the air.

(1) A condition near saturation must be reached before condensation will occur. In a vessel partially filled with water and with a stationary column of air above it, the water molecules escape into the air and continue their motion as water vapor. These vapor molecules, because of their motion, exert an increased pressure (called the *partial pressure* of the water vapor in the air column) back on the liquid surface. The partial pressure of the water vapor is independent of the partial pressures of the other gases in the air. The rate at which the molecules from the air enter the liquid water surface depends upon the frequency with which they strike the surface; which, in turn, depends upon the number and velocity of the water molecules in the air (the partial pressure of the water vapor in the air). As more and more molecules enter the vapor state, some will return to the liquid surface. When a condition of equilibrium is reached wherein the number of molecules leaving the liquid equals the number returning, the space above the liquid is said to be saturated and the pressure exerted by the water vapor molecules is called the *saturation vapor pressure* for the particular air and water temperature existing. When the air temperature is raised, the number of molecules necessary for saturation and their individual velocities are increased, thus raising

the saturation vapor pressure of the air; i.e., the air is able to hold more vapor molecules and is no longer saturated.

(2) As saturation in the atmosphere is approached, the presence of nuclei, such as those of dust and salt particles, are required to promote the actual condensation of the water vapor into liquid.

(3) Water vapor is a universal constituent of the atmosphere. There is a limit to the quantity of water vapor which can be contained in a given volume of air. If more and more water vapor is injected into a container of air, a condition will be reached in which the water will condense as fog in the container or as dew on its walls. If more water vapor is added, more will condense, and the total amount of vapor in the container will remain unchanged. The air in the container is then said to be saturated with water vapor.

(4) The quantity of water vapor in a saturated volume of air depends on the air temperature. The higher the temperature of the air, the greater is the tendency for liquid water to turn into vapor. At a higher temperature, more vapor must be injected into the given volume of air before the saturated condition will be reached. Conversely, cooling the saturated air will force some of the vapor to condense, and the quantity of vapor present will diminish.

b. Dew Point. The dew point is that temperature to which air (at constant pressure and with constant water vapor content) must be cooled to become saturated. For example, if the air temperature were 60° F. and the dew point 50° F., the air would be saturated if cooled to 50° F. If the air were further cooled to 49° F., it could no longer hold all the water

vapor present—some of it would be virtually “squeezed out” in the form of liquid water; condensation would have taken place. If this cooling took place only in the fraction of an inch or so of the air above the ground, dew would form; however, it is more likely that the cooling will affect a deeper layer of the lower troposphere and fog will form. The dew point is important to the Army aviator because it indicates the temperature at which fog will normally start to form. When the air is saturated, the relative humidity is 100 percent; if the air is not saturated, the temperature is a higher value than the dew point and the relative humidity is less than 100 percent. The greater the spread between the temperature (T) and the dew point (T_d), the more remote is the possibility of fog formation. Generally, condensation will not occur when the spread exceeds 4°F .

c. Specific Humidity.

(1) The moisture content of the air can be measured by expressing the humidity as the amount of water vapor (in grams) contained in one kilogram of natural air. This is called the *specific humidity*. A kilogram of air will carry the same number of grams of water vapor with it wherever it goes, unless more water vapor is added by evaporation or removed by cooling and condensation. The moisture content can also be expressed as a weight per unit volume (absolute humidity), but this ratio would change any time the atmospheric temperature or pressure changed.

(2) The Army aviator should be able to interpret

and recognize the significance of specific humidity (high or low). The greatest quantity of water vapor for condensation and/or sublimation is available in air masses having a high specific humidity. To an aviator, the temperature of the dew point (T_d) is an indicator of the quantity of water vapor in the air; the higher the dew point, the greater the amount of water vapor in the air. In the normal range of temperatures over the surface of the earth, a doubling of the water vapor content of the air is represented by an approximate 20°F . rise in the dew point (fig 2-13). If, for example, a kilogram of air with a dew point of 60°F . contains 11 grams of water vapor, a kilogram of air with a dew point of 80°F . contains about 22 grams of water vapor. Conversely, if a saturated parcel of air at 80°F . is cooled to 60°F ., 11 grams of water would have to be released through the condensation process. This condensation gives off heat energy to the atmosphere, and the heat energy may be realized as turbulence in clouds.

d. Relative Humidity. Most of the atmosphere is not saturated; it contains less than the maximum possible quantity of water vapor. For weather analysis, it is desirable to be able to express how *near* the air is to being saturated.

(1) Relative humidity (RH) is defined as the ratio of the amount of water vapor contained in the air to the amount of water vapor that the air would contain when saturated at the same temperature. It is expressed as a percentage, with satu-

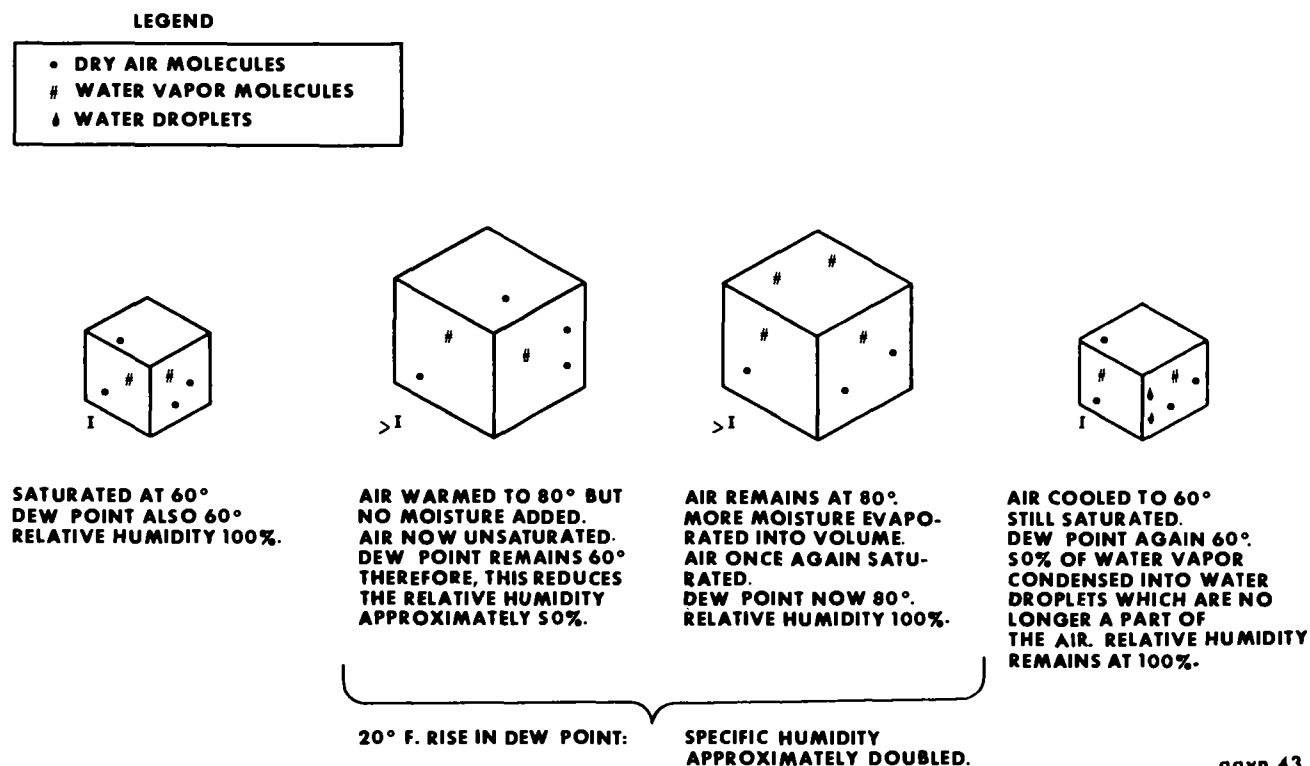


Figure 2-13. Diagrammatic illustration of dew point.

rated air having 100 percent relative humidity.

(2) Relative humidity is related to the spread (difference) between the temperature and the dew point. The temperature of the dew point is raised by increasing the actual moisture content of the air—actual vapor pressure. If the T_d were exactly equal to the T , the air would be saturated. The actual air temperature, therefore, controls the maximum amount of moisture the air could contain—saturation vapor pressure. Thus the equation for relative humidity may be expressed as—

$$RH = 100 \times \frac{\text{actual vapor pressure}}{\text{saturation vapor pressure.}}$$

(3) For example (fig 2-13), an air parcel with T of 80°F. , T_d of 60°F. , and RH of 50 percent has a saturation vapor pressure corresponding to $T = 80^\circ\text{F.}$; however, it can hold twice as much water vapor as is present since the relative humidity is 50 percent. An RH of 100 percent can be obtained by increasing the amount of water (water vapor) in the air until T_d has been raised to 80°F. ; an RH of 100 percent can also be reached by cooling the temperature to 60°F. Although the saturated parcel of air at 60°F. contains only one-half the moisture that the saturated parcel of air of 80°F. contains, both parcels have 100 percent relative humidity—a relative value depending upon the percentage of saturation.

e. Mixing Ratio. When air rises, it expands and contains fewer molecules per cubic meter. Mixing ratio is the method of indicating the moisture content of the air so that the ratio of water vapor to air will not change when the atmospheric pressure or temperature changes. Mixing ratio is defined as the ratio of the density of the water vapor present to the density of the dry air; it is usually expressed as the number of grams of water vapor per kilogram of dry air. For practical purposes, the mixing ratio remains constant with changes in air temperature and pressure so long as no moisture is added or removed.

f. Saturated Mixing Ratio. Air at a given temperature can hold only a certain amount of water vapor before it is saturated. The total amount (weight) of vapor which a given weight of dry air will hold at a specific temperature and pressure is referred to as the *saturated mixing ratio*. The following relationship exists between mixing ratio, saturated mixing ratio, and relative humidity:

$$\text{relative humidity} = \frac{\text{mixing ratio}}{\text{saturated mixing ratio}} \times 100.$$

Note. If any two of the three components in this relationship are known, the third can be determined mathematically in the formula.

g. Distribution of Water Vapor. The part of the atmosphere which remains over tropical water may contain large amounts of water vapor (over 20 grams per kilogram) but, because of the high air temperature, will not be completely saturated. On the other hand, very cold air (at approximately 0°F.) may contain only 1 gram per kilogram, and yet become saturated, producing sublimation. The maximum weight of the water vapor in the atmosphere is rarely more than 4 percent of the total weight of the natural air.

2-13. Humidity Instruments

Two of the most common humidity measuring instruments are the hair hygrometer and the sling psychrometer.

a. Hair Hygrometer. The hair hygrometer operates on the principle that oil-free human hair stretches when wet. The amount of stretch is proportional to the degree of saturation of the air with water vapor (the variation in length of a properly treated hair is approximately logarithmic between the RH limits of 20 to 100 percent). The hair is mounted under tension to operate a dial (hygrometer) which indicates the relative humidity, or a pen which records the relative humidity directly (hygrograph). The hair hygrometer is subject to large errors and is slow to respond to changes.

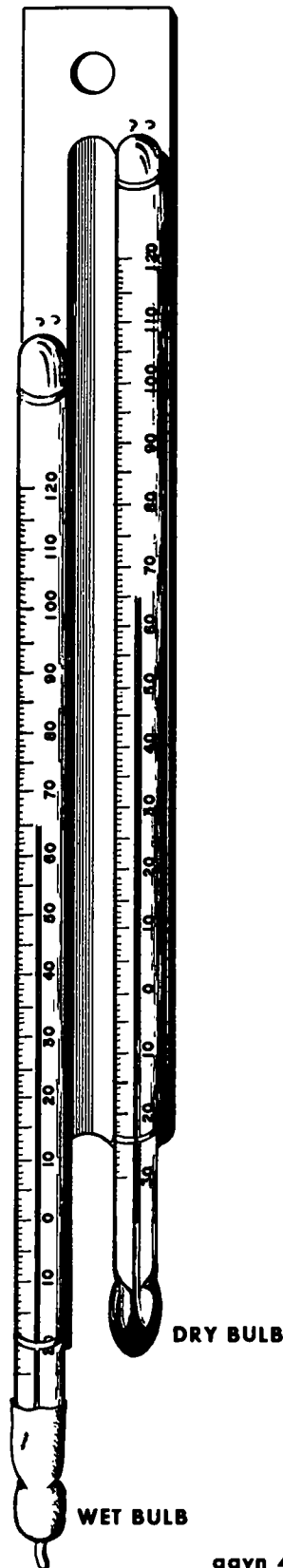
b. Sling Psychrometer. The sling psychrometer (fig 2-14), also known as the wet and dry bulb hygrometer, is more satisfactory than the hair hygrometer. This instrument consists of two thermometers, one of which is kept wet by a linen wick. The cooling of the wet bulb thermometer is proportional to the rate of evaporation of the water from the wick. The rate of evaporation depends on the relative humidity and the temperature of the surrounding air. When the air is very dry, evaporation from the wick will cool the wet bulb thermometer and its temperature indication will be lower than that of the dry bulb thermometer. When the air is saturated, there is no evaporation, so both thermometers give the same readings. Psychrometric tables are provided to obtain dew point and relative humidity from the air temperature given by the dry bulb thermometer and the temperature given by the wet bulb thermometer.

2-14. Precipitation

a. General. Precipitation is the general term for all forms of falling moisture (e.g., rain, snow, hail, ice pellets, and their modification). The chain of events that lead up to precipitation includes—

(1) Saturation of the air by cooling and/or increasing the water vapor content in the air.

(2) Condensation of the water vapor through the action of hygroscopic nuclei, forming clouds. Clouds



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Figure 2-14. Sling psychrometer.

may be composed of water droplets or ice crystals, or combinations of both, depending upon the temperature and the amount of convective activity in the cloud.

(3) Coalescence, or growth, of water droplets in size and weight. Much condensation occurs without producing precipitation; i.e., there are many clouds which do not result in rain. Clouds may be considered as colloidal suspensions of liquid and/or solid water in the air. An approximation of the radius of an average cloud droplet is .002 centimeter while the radius of an average rain drop is approximately .1 centimeter. Since volume is proportional to the cube of the radius, an average rain droplet is made up of approximately one million cloud droplets. The tendency for these tiny cloud droplets to coalesce and produce larger droplets, which fall because of the gravitational attraction of the earth, is fostered by the following five conditions: (a) nonuniform electrical charges in cloud droplets (electrical attraction), (b) differences in sizes of cloud droplets (mass attraction), (c) temperature differences between cloud droplets (vapor pressure differences), (d) motion of the droplets (turbulent mixing), and (e) ice crystals (water droplets will evaporate and sublime on ice crystals, increasing the size of the ice particles). Combinations of these five conditions will determine the size of the precipitation particles falling from the clouds. In highly turbulent clouds which extend above the freezing level, both ice crystals and water droplets are present, causing rapid transfer of water from droplet to crystal through evaporation and sublimation. These highly turbulent clouds produce large amounts of rainfall during short periods of time.

b. Liquid Precipitation.

(1) *Rain*—precipitation which reaches the Earth's surface as relatively large droplets. Rain can be classified as light, moderate, or heavy. This classification is normally based on rate of fall or the effect it has on visible surfaces or on horizontal visibility.

(2) *Drizzle*—precipitation from stratiform clouds in the form of numerous drops of water much smaller in diameter than those occurring in rain. The fact that these minute drops reach the earth indicates the absence of turbulence. Drizzle is classified as light, moderate, or heavy. This classification is normally based on rate of fall or the restriction to horizontal visibility.

c. Freezing Precipitation.

(1) *Freezing rain*—precipitation in the form of supercooled liquid raindrops, a portion of which freezes and forms a smooth coating of ice upon striking exposed objects (e.g., exposed aircraft components, runways, trees, powerlines, etc.).

(2) *Freezing drizzle*—precipitation in the form of supercooled drizzle which freezes in a manner similar to freezing rain.

d. Frozen Precipitation.

(1) *Ice pellets* (previously called sleet)—frozen raindrops formed by rain or drizzle falling through a layer of air with temperatures below freezing until the drop is frozen to an ice pellet.

(2) *Hail*—precipitation of balls or irregular lumps of ice. Hail results when waterdrops, below the freezing level, are repeatedly carried above the freezing level by currents in a thunderstorm. The drops freeze into ice pellets, start falling, and accumulate a coating of water. Carried upward again by an ascending current of air, the coating freezes, enlarging the diameter of the hailstone. This process, repeated a number of times, can produce hailstones weighing as much as 2 pounds.

(3) *Snow*—precipitation composed of ice crystals. When atmospheric water vapor sublimates at temperatures below 0° C., ice crystals may form and fall to the ground, usually as snowflakes or combinations of individual ice crystals.

2-15. Hydrologic Cycle

Water at the earth's surface evaporates by absorbing heat energy. The water vapor is transported horizontally and vertically by atmospheric currents until it releases its energy to the atmosphere through condensation in forming clouds and fog. The water cycle is completed when precipitation returns the water to the surface. This evaporation-condensation cycle is a part of the thermodynamics involved in the series of water phenomena called the *hydrologic cycle*. The phases of the hydrologic cycle are—

- a. Precipitation from clouds falls on sea and land.
- b. Water flows from land to sea as runoff or seepage.
- c. Evaporation from precipitation and all moist surfaces, and transpiration from plants and animals, supply water vapor for the atmosphere.
- d. Condensation and sublimation of water vapor produces clouds, completing the cycle. Throughout the cycle, the earth and its atmosphere neither gains nor loses moisture.

Section IV. PRESSURE

2-16. Pressure

a. *Pressure* is force per unit area ($P = F/A$). The pressure exerted by a fluid (gas or liquid) varies with the height of the fluid column and the density of the fluid. The pressure exerted on or by a fluid is distributed uniformly throughout the fluid in all directions, and is independent of the orientation of the surface on which it acts.

b. *Atmospheric pressure* is the pressure exerted by the atmosphere as a result of gravitational attraction acting upon the column of air lying directly above a point. As a result of the constant and complex air movements and the changes in temperature and moisture content of the air, the weight of the air column over a fixed point is continually fluctuating. These changes in weight, and therefore pressure, are imperceptible to the human senses, but are measurable with pressure-sensitive instruments.

2-17. Pressure Instruments

The instruments commonly used in the measurement of atmospheric pressure are the mercurial barometer (or mercury barometer), the aneroid barometer, and the barograph.

a. *Mercurial Barometer*. Figure 2-15 shows the principle of the mercurial barometer. The weight of the atmosphere presses down on the mercury in container A and supports the column of mercury inside the glass tube B from which all air has been removed. The weight of the mercury column corresponds to the weight of the atmosphere. In the illustration (fig 2-15) the column of mercury is 29.92 inches high; the

atmospheric pressure, therefore, is equal to the weight of a column of mercury that is 29.92 inches in height. The conversion of height to weight exerted (force) per unit area may be accomplished as follows:

(1) A cubic inch of mercury (C, fig 2-15) weighs 0.491 pounds.

(2) If three such cubes were placed in a container (D, fig 2-15) the bottom surface would be under a pressure of 3×0.491 , or 1.473 pounds per square inch.

(3) Replacing the 3 inches with the 29.92 inches of mercury in the glass tube results in the equation— $29.92 \times 0.491 = 14.69$ pounds per square inch.

b. *Aneroid Barometer*. The activating unit of an aneroid barometer is a metal bellows containing a partial vacuum. The bellows expands or contracts in response to changes in atmospheric pressure. A pointer, linked to the bellows, moves across a calibrated dial, thereby constituting the indicator mechanism (fig 2-16). Although not as accurate as the mercurial barometer, the aneroid barometer is useful because of its compact and rugged construction.

c. *Barograph*. The barograph is an aneroid barometer which produces a continuous record of atmospheric pressure (fig 2-17).

2-18. Units of Pressure Measurement

Inches of mercury and *millibars* are two pressure units of which every aviator must have a knowledge. He uses these units during each flight and in each weather briefing by the forecaster.

a. *Inches of Mercury (Hg)*. The most common unit

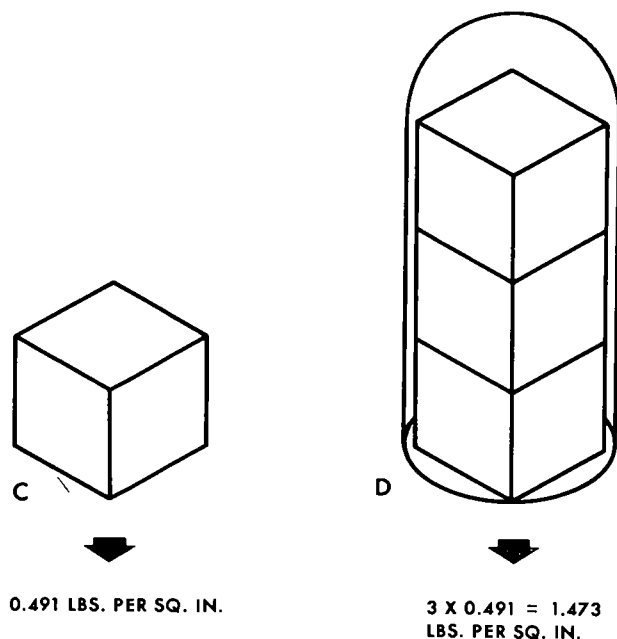
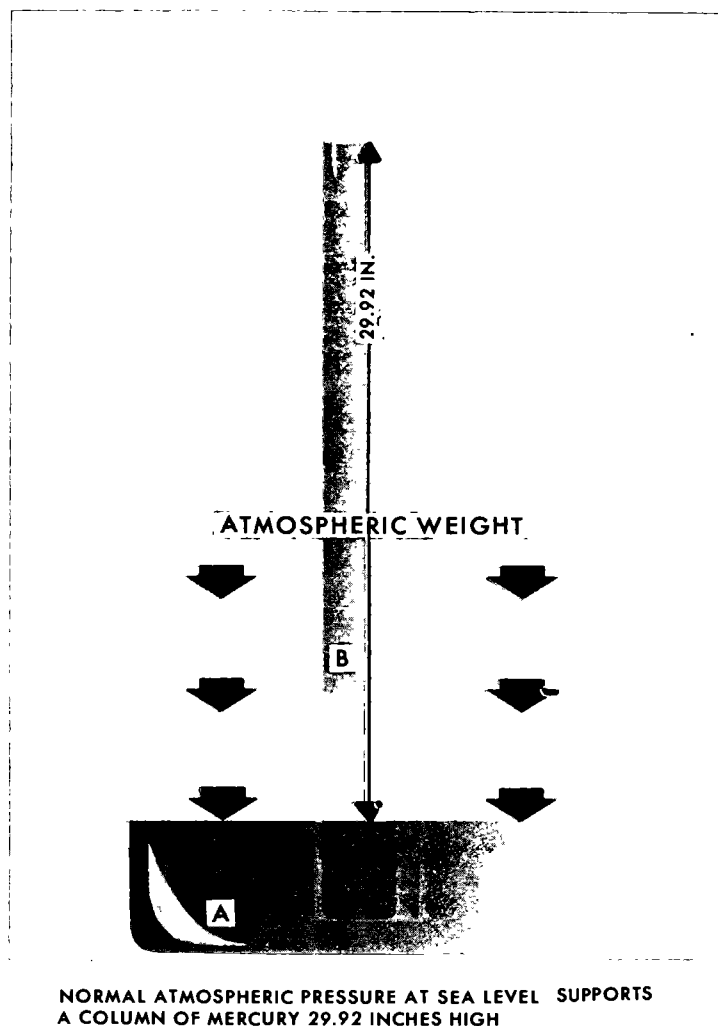


Figure 2-15. Principles of the mercurial barometer.

is the inch of mercury, derived from the height of the mercury column in a mercurial barometer. Since the inch is a unit of length, this system does not directly express the force per unit area (pressure) that the atmosphere exerts. Since the Kollsman window of pressure altimeters in United States aircraft is calibrated for settings in inches of mercury, aviation agencies of the United States government express altimeter settings in inches of mercury.

b. Millibar. In meteorology, it is more convenient to express the pressure directly as a force per unit area. This is done by using a unit called the millibar (mb), which is an atmospheric pressure equal to a force of 1,000 dynes per square centimeter.

(1) Many foreign nations use the millibar for altimeter settings. Aviators flying in these countries will need a conversion table (millibars to inches of mercury) in the aircraft and a general familiarity with the millibar as a unit of pressure.

(2) Standard atmospheric pressure at sea level is 1013.2 millibars, which is the equivalent of 29.92 inches of mercury. The pressure exerted by 1 inch of

mercury is equivalent to approximately 34 millibars, and the pressure exerted by 1 millibar is equivalent to approximately 0.03 inch of mercury.

2-19. Sea Level Atmospheric Pressure

a. When charting atmospheric pressures over various areas of the earth, the meteorologist is mainly interested in the pressure difference per unit distance—the pressure gradient. He is not interested in the small differences in the acceleration of gravity which vary with latitude, elevation, and effects of mountains. To minimize these variations, all observations (with the exception of altimeter settings) are reduced to sea level gravity at 45° latitude.

b. In order to compensate for pressure variations because of different station elevations, all observations are mathematically corrected to “mean sea level (MSL).”

c. Altimeter settings are obtained by mathematically reducing station pressure to mean sea level. This enables the pilot to read MSL altitudes on his altim-

eter. No gravity reduction is applied to altimeter settings.

d. The standard or normal atmospheric pressure at sea level at a standard air temperature of 15° C. is 1013.2 millibars, 29.92 inches of mercury, or 14.7 pounds per square inch. However, standard atmospheric pressure seldom exists at a given station. Normal sea level pressures of the atmosphere vary from as low as 950 millibars (about 28 inches) to as high as 1050 millibars (about 31 inches). Such variations in pressure indicate the dynamic nature of the atmosphere.

2-20. Determining Pressure Systems

To eliminate pressure variations caused by stations being at different altitudes, the mean sea level pressure is plotted in millibars at each reporting station on a surface weather map. Lines (isobars) are drawn connecting equal values of reported mean sea level pressure. The isobars and appropriate labels in millibars (mb) outline pressure areas in somewhat the same manner as contour lines outline terrain features on contour maps. Standard procedure on maps of North America is to draw isobars for every 4 millibars. The isobaric pattern is never the same on any



Figure 2-16. Aneroid barometer.

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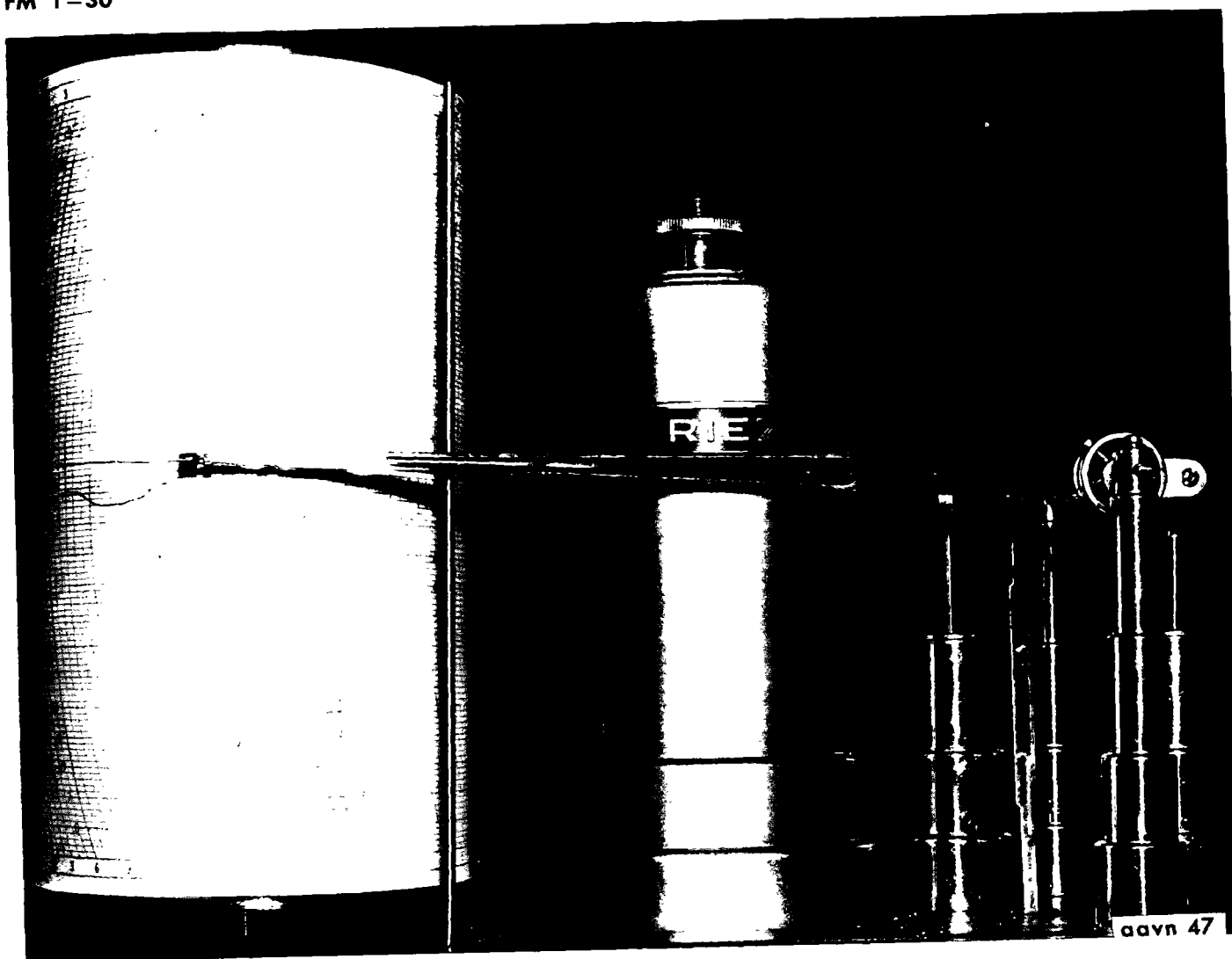


Figure 2-17. Barograph.

two weather maps; however, they do show patterns of similarity. The pressure patterns and systems (shown by the configuration of the isobars) which have a definite meaning to the aviator are shown in figure 2-18.

a. Low.

(1) A low is a pressure system in which the barometric pressure decreases toward the center, and the windflow around the system is counterclockwise in the Northern Hemisphere. The terms *low* and *cyclone* are interchangeable. Any pressure system in the Northern Hemisphere with a counterclockwise (cyclonic) windflow is a cyclone.

(2) Low pressure systems with severe storm characteristics are called hurricanes, typhoons, tropical storms, tornadoes, or waterspouts to identify the exact nature of the storm.

(3) Unfavorable flying conditions in the form of low clouds, restricted visibility by precipitation and fog, strong and gusty winds, and turbulence are common in low pressure systems.

(4) Thermal lows caused by intense surface heating and resulting low air density over barren continental areas, are relatively dry with few clouds and practically no precipitation. These thermal lows are almost stationary and predominate over continental areas in the summer.

(5) Migratory lows of the secondary circulation are discussed in paragraph 4-7.

b. High.

(1) A high is a pressure system in which the barometric pressure increases toward the center, and the windflow around the system is clockwise in the Northern Hemisphere. The terms *high* and *anticyclone* (opposite of cyclone) are interchangeable. Any pressure system in the Northern Hemisphere with a clockwise (anticyclonic) windflow is an anticyclone.

(2) Flying conditions are generally more favorable in highs than in lows because of less clouds, better daytime visibility, light or calm winds, and less-concentrated turbulent areas.

(3) High pressure systems predominate over cold surfaces (where the air is dense). They are more intense over continental areas in winter and oceanic areas in summer. Centers of high pressure rarely exist south of 23° N. latitude in the Northern Hemisphere.

(4) In the Northern Hemisphere, a general cycle of highs and lows moves through the Temperate Zones from west to east. The movement of the pressure systems is more rapid in the winter season when the cyclones are most intense and the anticyclones extend farthest to the south.

c. Col. A *col* is a saddleback region between two highs or two lows. The weather is erratic and unpredictable because of the flat pressure gradient.

d. Trough. A *trough* is an elongated area of low pressure, with the lowest pressure along the trough line. The weather in a trough is frequently violent.

e. Ridge. A *ridge* is an elongated area of high pressure with highest pressure along the ridge line. The weather in a ridge is generally favorable for flying.

2-21. Pressure Gradient

The rate of change in pressure in a direction perpendicular to the isobars is called *pressure gradient*. Pressure applied to a fluid is exerted equally in all directions throughout the fluid; e.g., if a pressure of 1013.2 millibars is exerted downward by the atmosphere at the surface, this same pressure is also exerted

outward in the atmosphere at the surface. Therefore, a pressure gradient exists in the horizontal (along the surface) as well as the vertical (with altitude) plane in the atmosphere.

a. Horizontal Pressure Gradient. The horizontal pressure gradient is *steep* or *strong* when the isobars determining the pressure system (fig 2-19) are close together. It is *flat* or *weak* when the isobars are far apart.

b. Vertical Pressure Gradient. If isobars are considered as depicting atmospheric topography, a high pressure system represents a hill of air, and a low pressure system represents a depression or valley of air. The vertical pressure gradient always indicates a decrease in pressure with altitude, but the rate of pressure decrease (gradient) varies directly with changes in air density with altitude. Below 10,000 feet altitude, pressure decreases approximately 1 inch per 1,000 feet in the standard atmosphere. The vertical cross section through a high and low (A, fig 2-20) depicts the vertical pressure gradient. A surface weather map view of the horizontal pressure gradient in the same high and low is illustrated by B of figure 2-20.

2-22. Pressure Altimeter

a. General. An altimeter is primarily an aneroid barometer calibrated to indicate altitude in feet in-

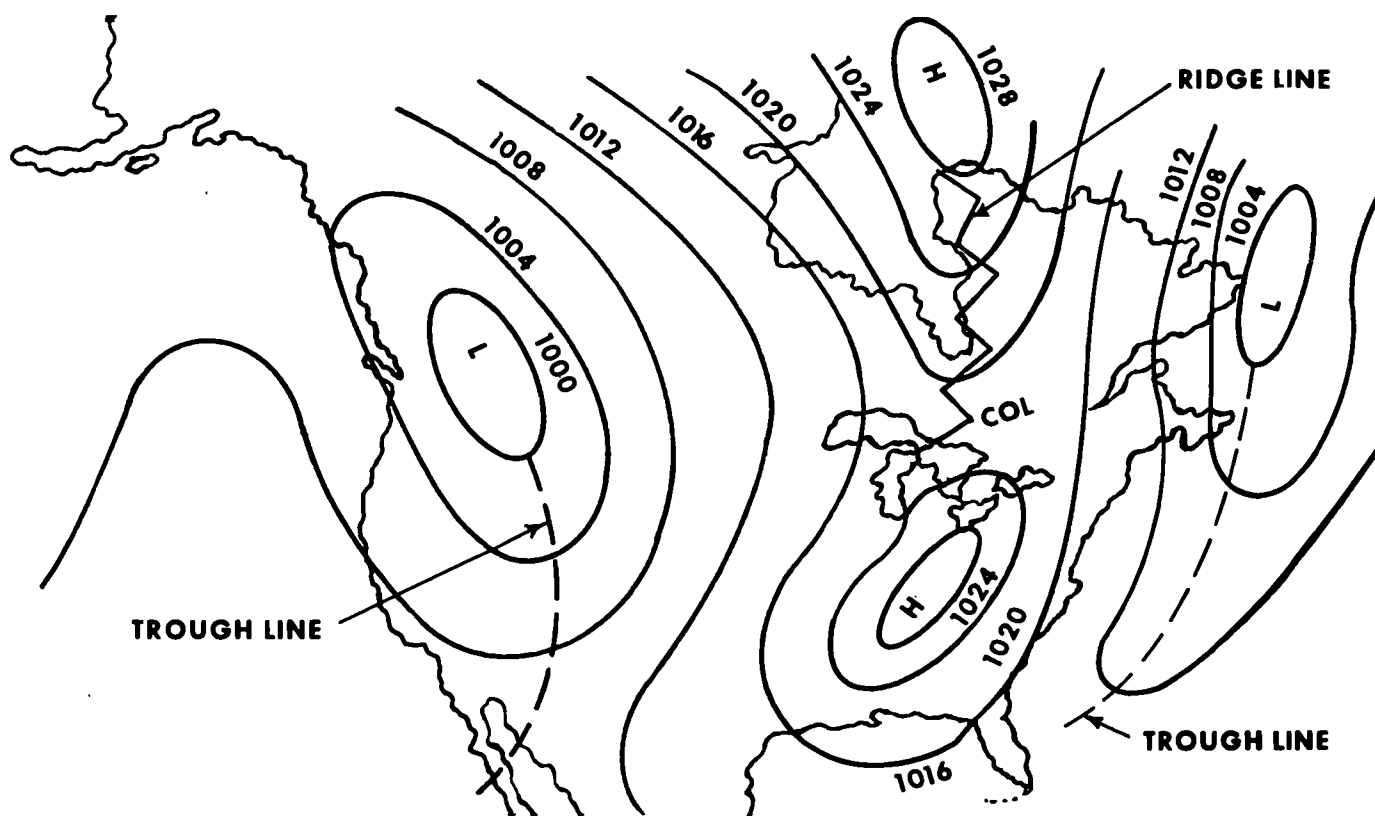
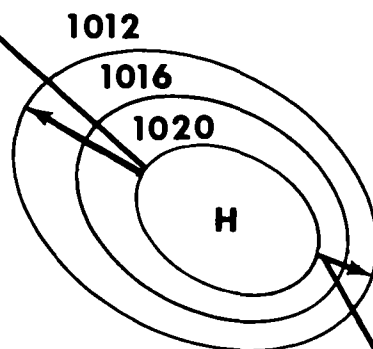


Figure 2-18. Pressure systems.

WEAK OR FLAT PRESSURE GRADIENT



STRONG OR STEEP PRESSURE GRADIENT

Figure 2-19. Principle of pressure gradient.

stead of units of pressure. An altimeter reads accurately only in a standard atmosphere and when the correct altimeter setting is used. Since standard conditions seldom (if ever) exist, the altimeter reading usually requires correction. An altimeter is *only* a pressure-measuring device. It will *indicate* 10,000 feet when the pressure is 697 millibars, whether or not the altitude is *actually* 10,000 feet.

b. Adjustment for Nonstandard Pressure. Because of the variations in pressure at sea level, altimeters are designed to permit adjustment to correct for non-standard sea level pressure.

(1) A procedure used in aircraft on the ground is to set the altimeter reading to the elevation of the airfield. The altimeter then reads the altitude above sea level and the Kollsman window indicates the current altimeter setting.

(2) The atmospheric pressure frequently differs at the point of landing from that at takeoff; therefore, an altimeter correctly set at takeoff may be in considerable error at the time of landing. For a safe landing under conditions of poor visibility or low ceiling, it is essential that the altimeter be set to indicate the correct altitude. Altimeter settings can be obtained in flight by electronic navigation and/or communication aids. Otherwise, the expected altimeter setting for landing should be obtained before takeoff. A knowledge of the existing pressure system will be helpful if an accurate setting is unobtainable.

(3) Figure 2-21 shows the pattern of isobars (or isobaric surfaces) in a cross section of the atmosphere from New Orleans, La., to Miami, Fla. The pressure at Miami is 1019 millibars and the pressure at New Orleans is 1009 millibars, a difference of 10 millibars. Assuming that an aircraft departs from Miami on a flight to New Orleans at an en route altitude of 500

feet, a decrease in mean sea level pressure of 10 millibars from Miami to New Orleans would cause the aircraft to gradually lose altitude; and although the altimeter would indicate 500 feet, the aircraft would actually be flying at approximately 200 feet over New Orleans. The correct altitude can be determined by obtaining the correct altimeter setting from New Orleans and resetting the altimeter to agree with the destination adjustment.

(4) The following relationships generally hold true up to approximately 15,000 feet:

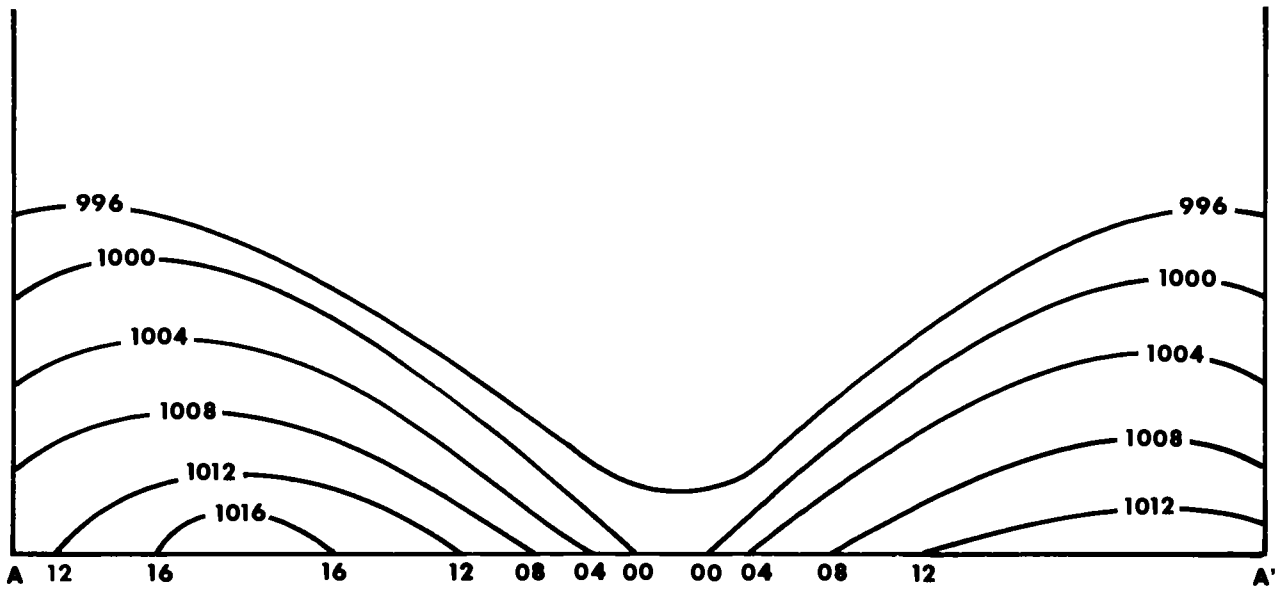
34 millibars = 1 inch (Hg) = 1,000 feet elevation

Note. Since 1 millibar is equal to about 30 feet (below 10,000 feet altitude), a change of 10 millibars (which is common) would result in an error of about 300 feet.

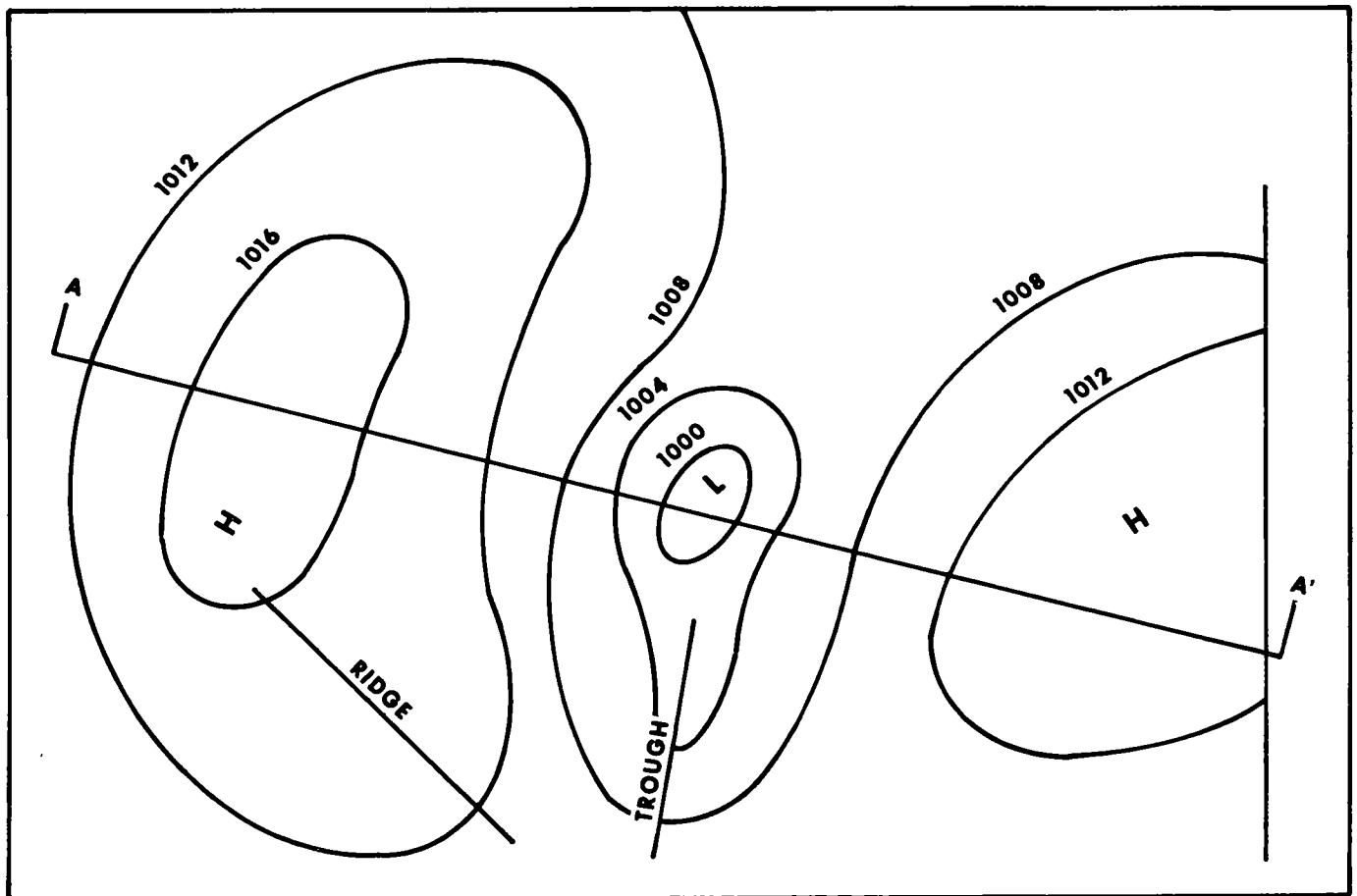
c. Error Due to Variation From Standard Temperature. Another type of altimeter error is due to non-standard temperatures. Even though the altimeter is properly set for surface conditions, it often will be incorrect at higher levels.

(1) If the air temperature at flight altitude is warmer than standard, the average pressure decrease per 1,000 feet between the aircraft and the surface is also less than standard (fig 2-22). Therefore, an aircraft flying in warmer than standard air will normally be higher than the altimeter indicates (A, fig 2-23).

(2) Conversely, if the air temperature at flight altitude is colder than standard, pressure decrease with altitude is greater than standard (fig 2-22). Therefore, an aircraft flying in colder than standard air will be normally lower than the altimeter indicates (B, fig 2-23). Many accidents have occurred during instrument flight in cold weather because aviators



(A) CROSS SECTION ALONG THE LINE A AND A'



(B) MAP VIEW

Figure 2-20. High and low pressure systems.

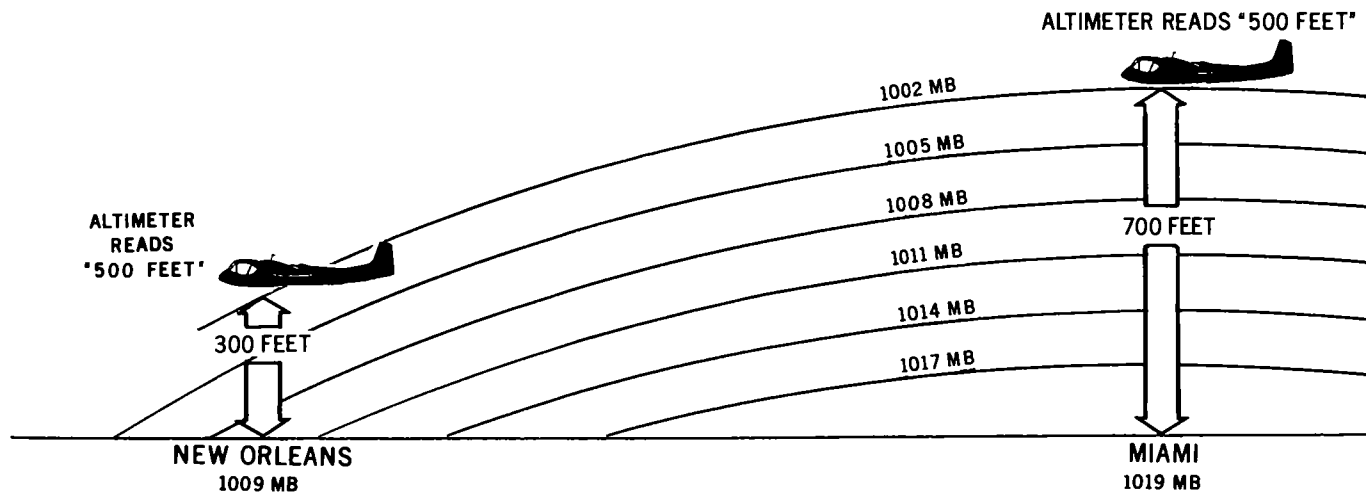


Figure 2-21. Altimeter errors due to change in surface pressure.

did not understand nor consider this altimeter error and failed to allow an adequate safety margin to clear mountainous terrain.

(3) The aviator does not attempt to correct his altimeter for nonstandard flight level temperatures. However, it is the aviator's responsibility to be aware of improper terrain clearance in temperatures much colder than standard.

(4) The amount of error caused by nonstandard temperatures can be obtained by use of the navigational computer. As a rule-of-thumb, the error is 2 percent of the altitude above the reporting station for each 5° C. variation from standard temperature.

Note. Standard temperature is 15° C. at sea level elevation with a lapse rate of 2° C. per 1,000 feet.

2-23. Density Altitude

Density altitude is defined as the pressure altitude corrected for temperature. (Pressure altitude is the distance measured from the 29.92-inch pressure level—the *standard datum plane*.) The theoretical performance of aircraft is evaluated by using standard atmospheric conditions (standard densities). In actual flight, standard atmospheric conditions are rarely, if ever, encountered. The efficiency of aircraft performance is greatly affected by the varying densities of the atmosphere. Changes in air density are caused by variations in atmospheric pressure and temperature. Changes in the water vapor content also affect the density of the air, but the amount is negligible (*note below*) in density altitude computation. An airfield may have a density altitude that varies several thousand feet from the mean sea level (MSL) elevation of the field. If the density altitude is higher than standard for the field, this field has a *high* (+) density altitude. An example of this would be an airfield at

5,000 feet (MSL) with a density altitude of 10,000 feet. Aircraft operating from this field would be in air of the same density that would normally be found in the standard atmosphere at 10,000 feet. The efficiency of the aircraft may be seriously affected in high density altitudes, especially when the aircraft is critically loaded. If the density altitude is lower (–) than normal for a given altitude, the efficiency of the aircraft is increased. An aviator operating from a field at 5,000 feet with a density altitude of 1,000 will be in the same air density at field elevation that normally exists at 1,000 feet.

Note. The moisture content of the air has very little effect on the density altitude. It increases the density altitude from approximately zero feet with a dew point temperature below 20° F. to (+) 250 feet with a dew point temperature near 100° F. For this reason, the moisture content is usually neglected when computing density altitude.

a. Affects on Aircraft Performance.

(1) The lift of an aircraft wing or blade is affected by the speed of the air around it and the density of the air through which it moves. Lift of a wing or blade will be increased by cold dense air in which the mass of air per unit volume passing around the wing or blade is at a maximum. In areas of high density altitude, a longer ground run for takeoff will be required for fixed wing aircraft. A helicopter may be required to make a ground run to establish effective translational lift for takeoff under such conditions.

(2) In areas of high density altitude, additional engine power to afford effective translational lift is required to compensate for the thin air. If the maximum gross weight of an aircraft exceeds the limits of available engine power in high density altitudes, a reduction in load (payload or fuel) is required. Since high density altitudes reduce the service ceiling of

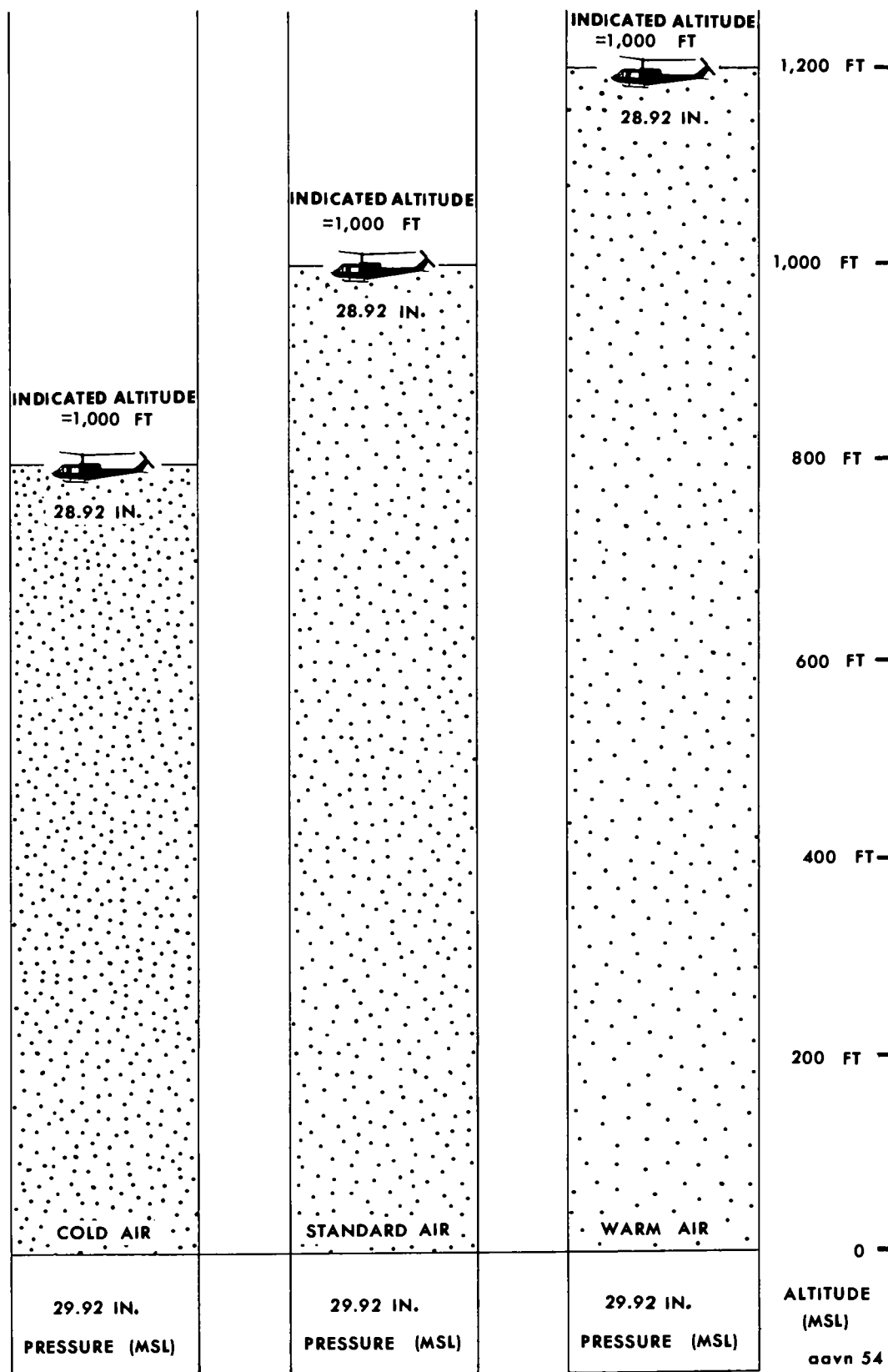
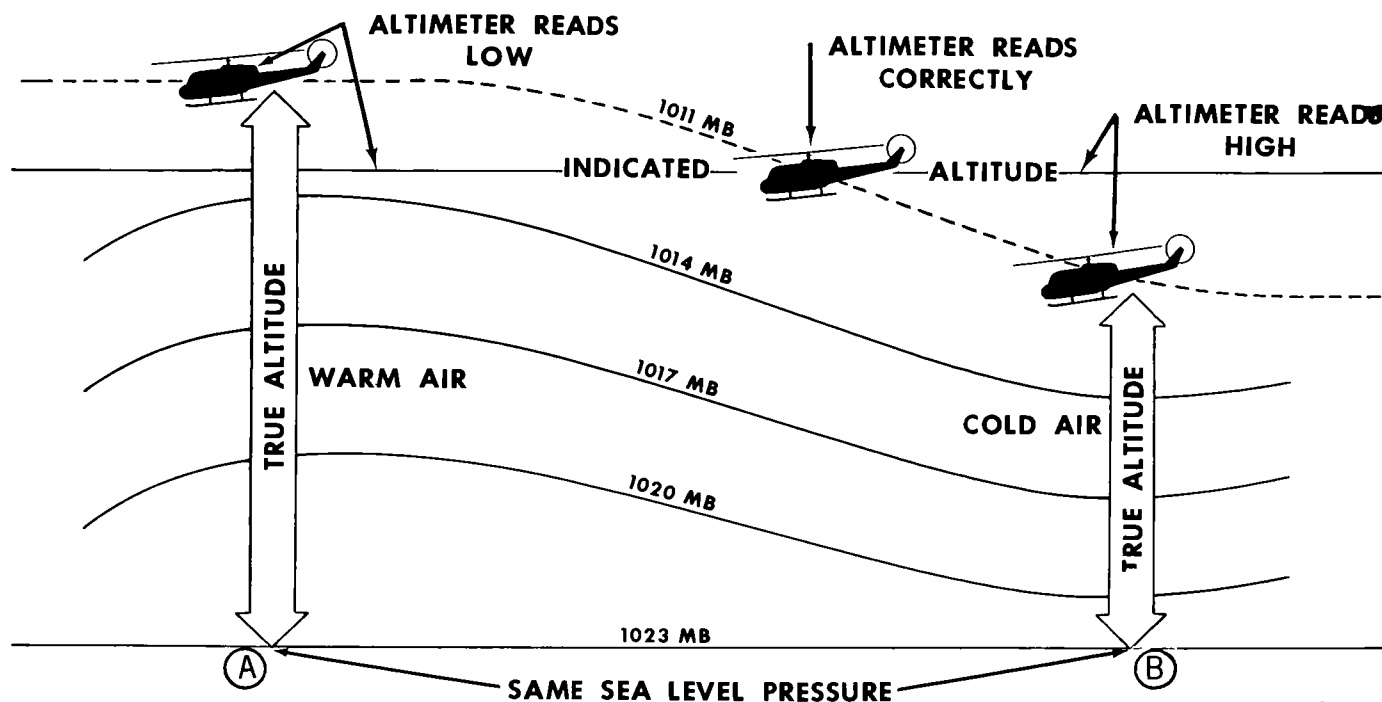


Figure 2-22. Density variation with temperature.



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Figure 2-23. Altimeter errors due to nonstandard air temperature.

aircraft, density altitude must be considered in computing maximum loads.

(3) The density altitude usually varies throughout the day with the movement of pressure systems, diurnal heating, and nocturnal cooling. The highest density altitudes are most common during the warmest hours. Air density decreases with an increase in altitude, temperature, or moisture content. Any change in air density will affect the performance of an aircraft.

(4) Wind velocity sufficient to afford translational lift while hovering will improve helicopter performance in areas of high density altitude. Strong winds also provide additional lift for fixed wing aircraft, and tend to counteract the effects of high density altitude.

b. Computing Density Altitude.

(1) The first step in computing density altitude is to determine the pressure altitude by setting 29.92 in the Kollsman window of the aircraft altimeter. Examples are as follows:

(a) *For pressures below standard.* If the field elevation is 1,500 feet with a current altimeter setting of 29.41 inches Hg—

Set altimeter to standard pressure 29.92 inches Hg.
 Altimeter now indicates 2,010 feet
 The pressure altitude is 2,010 feet

(b) *For pressure above standard.* If the field elevation is 2,000 feet with a current altimeter setting of 30.85 inches Hg—

Set altimeter to standard pressure 29.92 inches Hg.
 Altimeter now indicates 1,070 feet

The pressure altitude is 1,070 feet

(2) The second step in computing density altitude is to determine the effect of the actual air temperature on the air density. The standard temperature of the atmosphere is 15° C. at sea level with a decrease of 2° C. per thousand feet (standard temperature lapse rate). Each 1° C. variation from the standard temperature changes density altitude approximately 120 feet. If the actual temperature is below standard for the pressure altitude, the density altitude is lowered; if the temperature is above standard for the pressure altitude, the density altitude is raised. Temperature variation is incorporated into a formula for obtaining density altitude from a known pressure altitude.

(a) $PA + (120 \times V) = DA$, where—PA is pressure altitude.

120 is the temperature constant.

Vt is the variation of the actual air temperature from standard at the pressure altitude.

DA is density altitude.

(b) Sample problem for air temperature above standard:

Pressure altitude 2,010 feet.
 Actual surface temperature 30° C.
 Standard temperature for the pressure altitude 11° C.
 Temperature variation is +19° C.
 $DA = 2,010 + 120(30-11).$
 $DA = 2,010 + 120(19).$
 $DA = 2,010 + 2,280.$
 $DA = 4,290$ feet.

(c) Sample problem for air temperature below standard:

Pressure altitude -----1,070 feet.
Actual surface temperature -----6° C.
Standard temperature for the pressure altitude -----13° C.
Temperature variation is -----7° C.
DA = 1,070 + 120 (+6 - 13).
DA = 1,070 + 120 (-7).
DA = 1,070 + (-840).
DA = 1,070 - 840.
DA = 230 feet.

(3) Density altitude can also be determined by using a computer. Density altitude charts are available in most weather stations. Data on the length of runway necessary for fixed wing aircraft and power requirements for rotary wing aircraft in varying air densities can be found in the operator's manual (TM 55-aviation series-10) for the appropriate aircraft.



CHAPTER 3 CLOUDS

Section I. GENERAL

3-1. Cloud Formations and Definition

a. General. Cloud formations are the direct result of saturation-producing processes which take place in the atmosphere. The Army aviator must be able to identify those cloud formations which are associated with weather hazards. A close study of cloud types will also assist the Army aviator in his interpretation of weather conditions from weather reports. Table 3-1 lists the abbreviation and symbol of each cloud type discussed.

b. Cloud Definition. Clouds are visible condensed moisture, consisting of droplets of water or crystals of ice, having diameters varying from 0.0001 to 0.004 inch. They are easily supported and transported by air movements as slow as one-tenth of a mile per hour.

Table 3-1. International Cloud Classification, Abbreviations, and Weather Map symbols.

TABLE 3-1. INTERNATIONAL CLOUD CLASSIFICATION, ABBREVIATIONS, AND WEATHER MAP SYMBOLS.

BASE ALTITUDE	CLOUD TYPE	ABBREVIATION	SYMBOL
BASES OF HIGH CLOUDS USUALLY ABOVE 20,000 FEET.	CIRRUS	CI	
	CIRROCUMULUS	Cc	
	CIRROSTRATUS	Cs	
— 20,000 FEET —			
BASES OF MIDDLE CLOUDS RANGE FROM 6,500 FEET TO 20,000 FEET	ALTOCUMULUS	Ac	
	ALTOSTRATUS	As	
— 6,500 FEET —			
BASES OF LOW CLOUDS RANGE FROM SURFACE TO 6,500 FEET.	*CUMULUS	Cu	
	*CUMULONIMBUS	Cb	
	NIMBOSTRATUS	Ns	
	STRATOCUMULUS	Sc	
	STRATUS	St	
— SURFACE —			

*CUMULUS AND CUMULONIMBUS ARE CLOUDS WITH VERTICAL DEVELOPMENT. THEIR BASE IS USUALLY BELOW 6,500 FEET BUT MAY BE SLIGHTLY HIGHER. THE TOPS OF THE CUMULONIMBUS SOMETIMES EXCEED 60,000 FEET.

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3-2. International Classification of Clouds

a. General. The international cloud classification (table 3-1) is designed primarily to provide a standardized cloud classification. Within this classification, cloud types are usually divided into four major groups and further classified in terms of their forms and appearance. The four major groups are—

- High clouds.
- Middle clouds.
- Low clouds.
- Clouds with vertical development.

b. Subdivision. Within the high, middle, and low cloud groups are two main subdivisions. These are—

(1) Clouds formed when localized vertical currents carry moist air upward to the condensation level. These clouds are characterized by their lumpy or billowy appearance and are designated *cumuliform* type clouds, meaning “accumulation” or “heap.” Turbulent flying conditions are usually found in and below cumuliform clouds.

(2) Clouds formed when complete layers of air are cooled until condensation takes place. These clouds are called *stratiform* type clouds, meaning “spread out,” since they lie mostly in horizontal layers or sheets. Flight within stratiform clouds is relatively smooth.

Note. Cumuliform clouds may be merged with stratiform clouds.

c. Rainclouds and Fragmentary Clouds. In addition to the two main subdivisions discussed in *b* above, the word *nimbus*, meaning “raincloud,” is added to the names of clouds that normally produce heavy precipitation, either liquid or solid. For example, a stratiform cloud producing precipitation is referred to as *nimbostratus*, and a heavy, swelling cumulus cloud that has grown into a thunderstorm is referred to as *cumulonimbus*. Clouds which are broken into fragments are identified by adding the prefix *fracto* to the classification name. For example, fragmentary cumulus is referred to as *fractocumulus*.

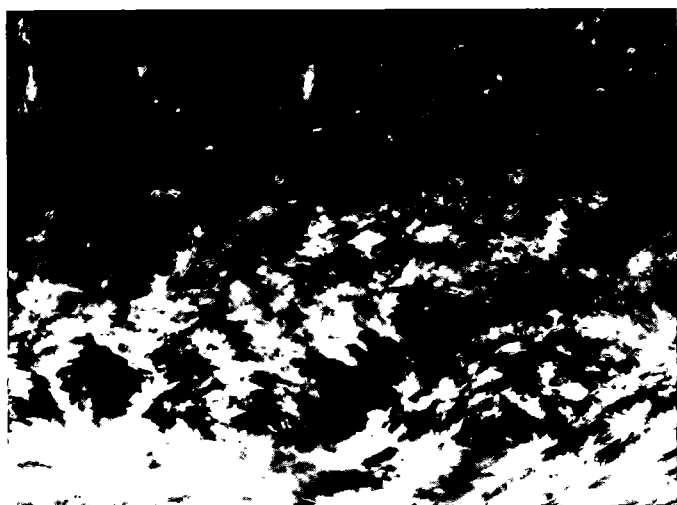
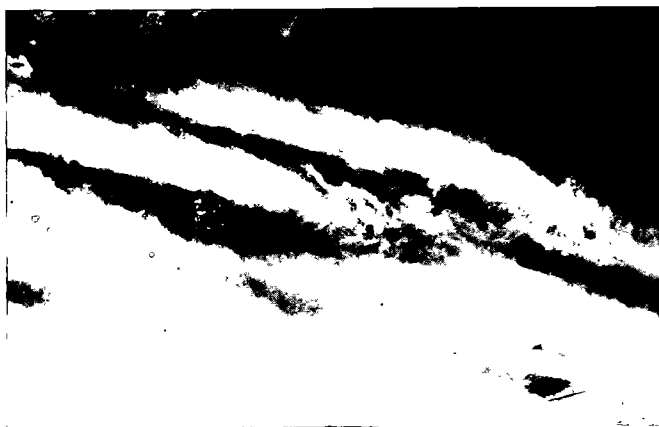
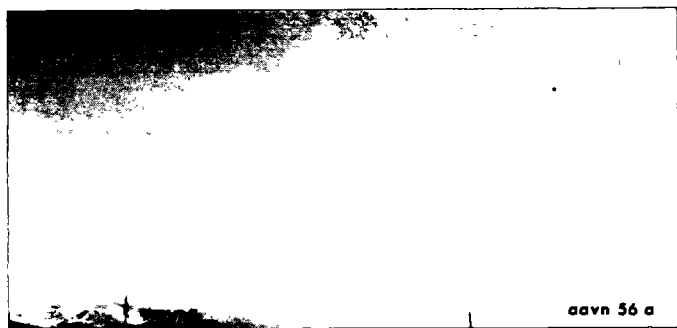


Figure 3-1. Cirrus clouds.

(Description: Detached clouds in the form of white, delicate filaments, or white or mostly white patches or narrow bands. These clouds have a fibrous (hairlike) appearance, or a silky sheen, or both.)

Section II. CLOUD TYPES

3-3. High Clouds

The high cloud group consists of *cirrus*, *cirrocumulus*, and *cirrostratus* clouds (fig 3-1, 3-2, and 3-3). The mean base level of these three cloud types is 20,000 feet or higher above terrain. Cirrus clouds give indications of approaching changes in weather. Cirriform clouds are composed of ice crystals and, because of this, do not present an icing hazard. These clouds are generally thin and the outline of the sun or moon may be seen through them, producing a halo effect.

3-4. Middle Clouds

The middle cloud group consists of *altocumulus* and *altostratus* clouds (fig 3-4 and 3-5). The altocumulus has many variations in appearance and in formation; whereas the altostratus varies mostly in thickness,

from very thin to several thousand feet. Bases of the middle clouds range from 6,500 to 20,000 feet above the terrain. These clouds may be composed of ice crystals or water droplets (which may be supercooled) and may contain icing conditions hazardous to aircraft. Altocumulus rarely produces precipitation, but altostratus usually indicates the proximity of unfavorable flying weather and precipitation.

3-5. Low Clouds

This group of clouds consists of *stratus*, *stratocumulus*, and *nimbostratus* clouds (fig 3-6, 3-7, and 3-8). The bases of these clouds range from near the surface to about 6,500 feet above terrain. Low clouds are of great importance to the aviator since they create low ceilings and poor visibility. The heights of the cloud



Figure 3-2. Cirrocumulus clouds.

(Description: Thin clouds without shading, composed of white patches or a sheet or layer, with very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged. They usually display brilliant and glittering quality suggestive of ice crystals.)

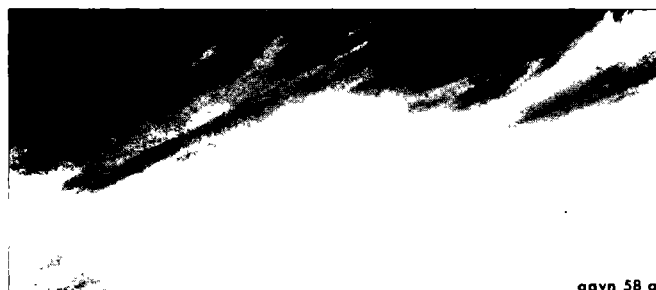


Figure 3-3. Cirrostratus clouds.

(Description: Thin, whitish cloud layers appearing like a sheet or veil, covering part of the sky or its entirety, and often thread-like or fibrous. They may be so light as to be barely visible or may be relatively dense.)

bases may change rapidly. If low clouds form below 50 feet, they are reclassified as fog and may completely blanket landmarks and landing fields. Low clouds have the same composition as middle clouds. In freezing or near freezing temperatures, they are a constant threat because of the probability of icing. When flying near or through these clouds, the Army aviator must be constantly alert to changes in cloud formation, ceiling, and visibility; and be prepared to fly to an alternate field if the ceiling or visibility

drops below minimums at his destination. (The navigation publications issued to Army aviators contain specific airport ceiling or visibility minimums.)

3-6. Clouds With Vertical Development

a. *Types.* Clouds with vertical development include the *cumulus* and *cumulonimbus* clouds (fig 3-9 and 3-10). These clouds generally have their bases below 6,500 feet above the terrain and tops sometimes extend above 60,000 feet. Clouds with vertical devel-

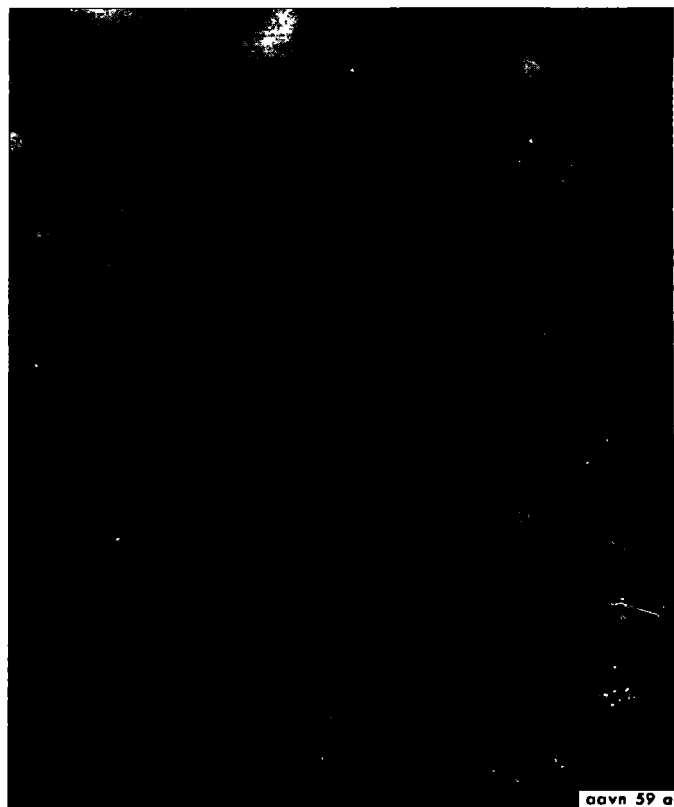


Figure 3-4. *Altocumulus clouds.*

(Description: White or gray clouds, or both white and gray, in patches or in sheets or layers, generally with shading and composed of rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged.)

opment are caused by some type of lifting action, such as convective currents, convergence, orographic lift, or frontal lift.

b. Flight Conditions Associated With Vertical Development Clouds. Scattered cumulus or isolated cumulonimbus clouds seldom present a flight problem since these clouds can be circumnavigated without difficulty. However, these clouds may rapidly develop in groups or lines of cumulonimbus. They may also become embedded and hidden in stratiform clouds, resulting in hazardous instrument flight conditions. Turbulence within cumulonimbus clouds may be severe enough to cause structural failure to the aircraft. (See chapter 10, Thunderstorms, and chapter 15, Radar and Weather.).

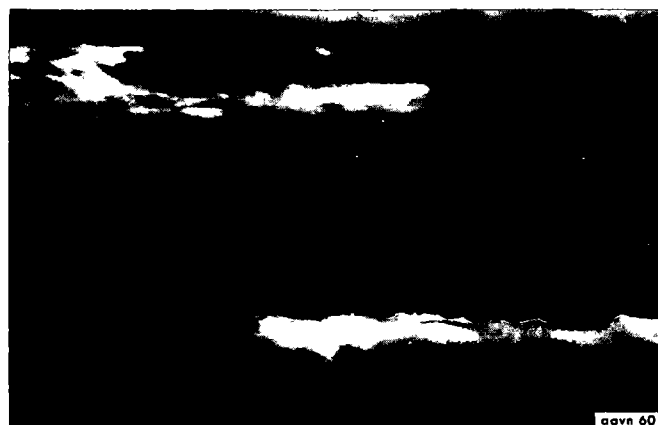


Figure 3-5. *Altostratus over a layer of stratocumulus.*

(Description: Gray to bluish, in a dense veil or layer with a fibrous, uniform composition. Light colors indicate relative thinness while dark colors indicate relative thickness.)

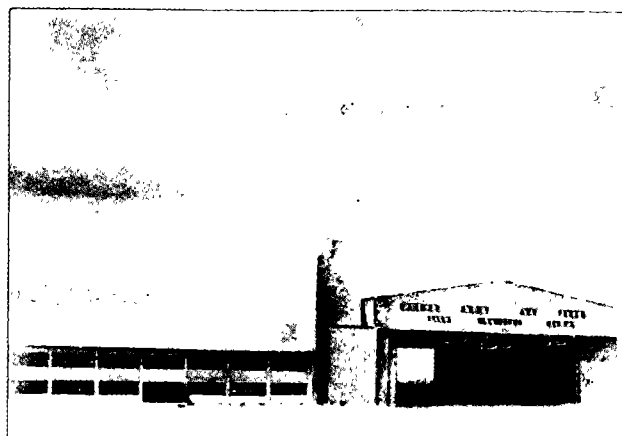


Figure 3-6. Stratus clouds.

(Description. Generally gray cloud layers with a fairly uniform base. They may produce drizzle, ice prisms, or snow grains. When the sun is visible through these clouds, its outline is clearly discernible. They sometimes appear in the form of ragged patches, and may be referred to as fractostratus or scud.)

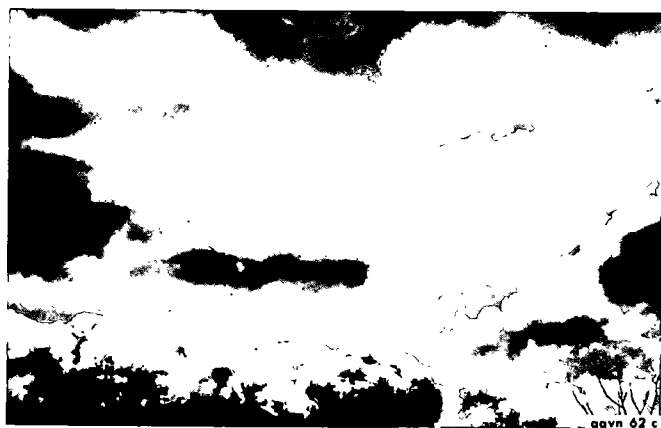


Figure 3-7. Stratocumulus clouds.

(Description: Gray or whitish or both gray and whitish clouds that usually have dark spots. These clouds are composed of rounded masses, rolls, etc., which may or may not be merged. Stratocumulus is often, particularly in the early morning hours, a transitional stage of cloud development between stratus and cumulus.)



Figure 3-8. Nimbostratus clouds.

(Description: Gray cloud layers, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. They are thick enough throughout to blot the sun. Low, ragged clouds (scud) frequently appear below the nimbostratus layer and may or may not merge with the nimbostratus.)

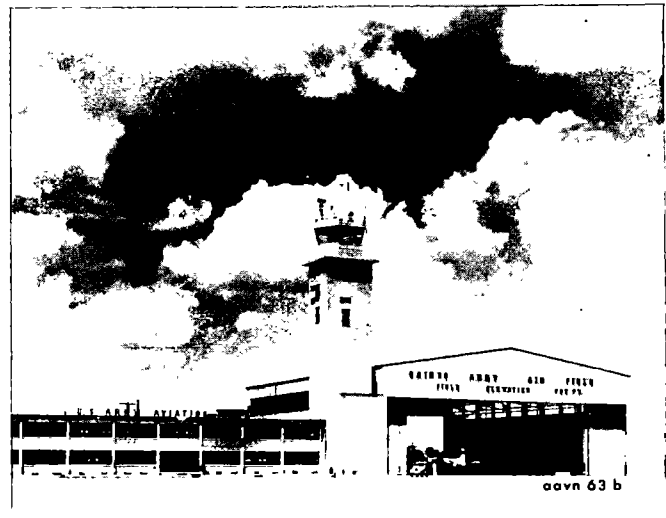


Figure 3-9. Cumulus clouds.

(Description: Detached clouds that are generally dense and with distinct outlines, developing vertically in the form of rising mounds, domes, or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white, with their bases relatively dark and nearly horizontal. They vary in size from light, fluffy powder-puff forms to towering masses.)

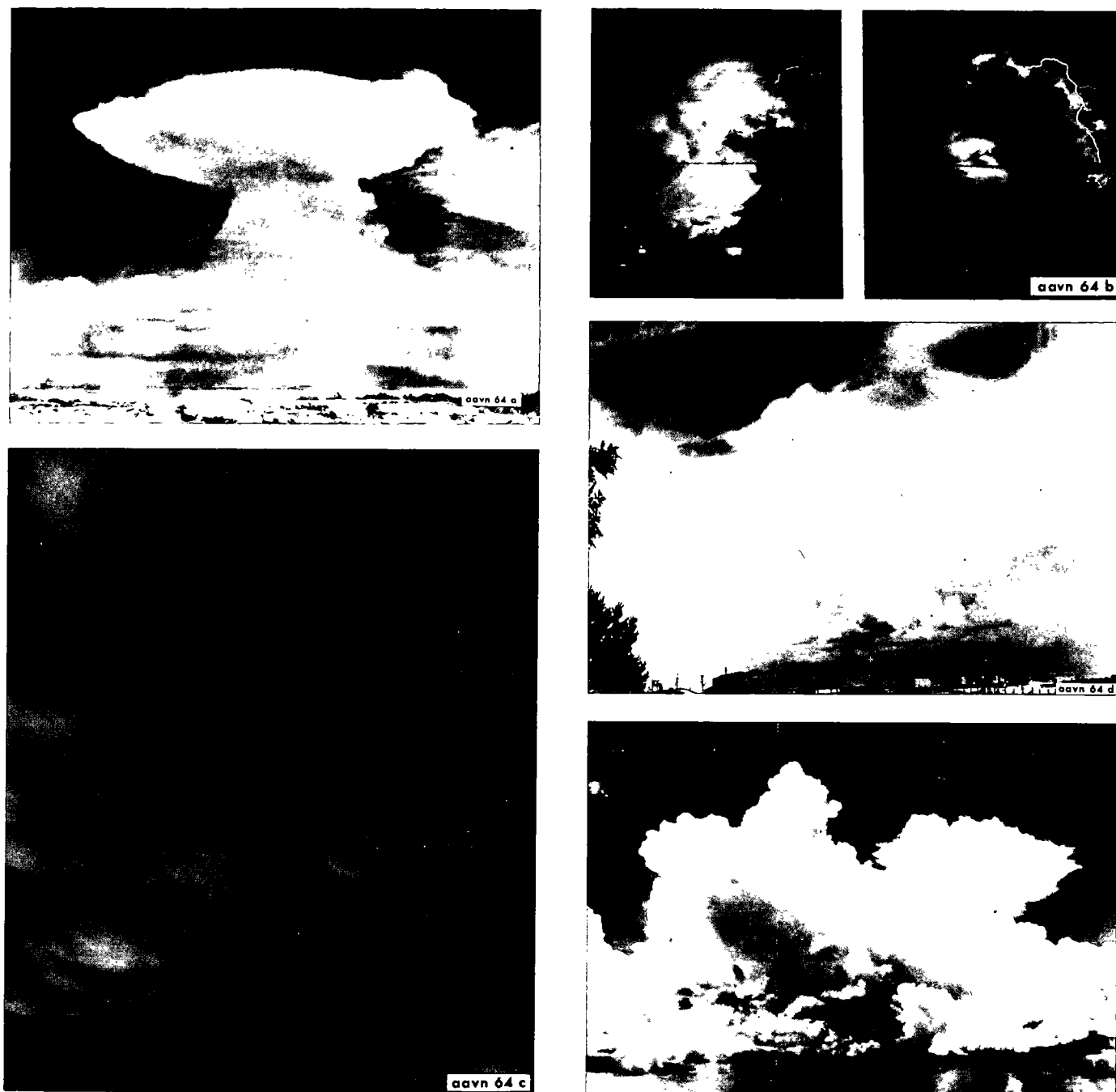


Figure 3-10. Cumulonimbus (thunderstorm) clouds.

(Description: Heavy and dense clouds with considerable vertical extent in the form of mountains or huge towers. They may be embedded in stratoform clouds, isolated, may appear in groups, or may appear in lines extending hundreds of miles. At least part of their upper portion is usually smooth, fibrous, or striated, nearly always flattened, and often spreads out in the shape of an anvil or vast plume. Under the base of this type cloud, which is often very dark, there are frequently low ragged clouds, either merged or not merged. The intensity of precipitation varies from light showers to very heavy rain. Cumulonimbus produces lightning, thunder, gusty winds, and often hail.)



CHAPTER 4 ATMOSPHERIC CIRCULATION

Section I. GENERAL CIRCULATION

4-1. General

a. On all flights the Army aviator is concerned with the wind. Knowledge of winds near the surface is important in landing and taking off, and in low flight; knowledge of winds at higher levels is essential in computing flight headings, time en route, time over reporting positions, destinations, alternates, and in some situations, the degree of turbulence.

b. The energy that sets the atmosphere into motion is obtained from the sun's radiation. Because of the relative position of the earth with respect to the sun, the earth receives much more radiation near the Equator than at the poles. This unequal heating by the sun's radiation at the earth's surface is the basis for atmospheric circulation. Variations in surface temperature in different localities, in the topography of the earth, and in rotational forces complicate the basic circulation pattern. For this reason, introducing atmospheric circulation as if the earth were a non-rotating sphere of uniform surface with the primary heat source at the Equator provides a good foundation for atmospheric circulation as it actually exists.

4-2. Simple Circulation

a. Definition. Circulation, in terms of meteorology, is the movement of air over the surface of the earth. This movement occurs throughout the entire atmosphere; however, this chapter will be limited to the movement of air in the troposphere.

b. Causes. The air within the troposphere (fig 2-2) is subject to continuous changes in density and temperature. Since air is a fluid, it reacts to these changes in density in much the same manner as confined liquids. When there is a difference in density between two or more portions of a confined liquid, the fluid will begin to move (circulate) within the container. When the differences in density of the air occur in the atmosphere, the air will also begin to circulate. Differences in air density are normally the result of temperature differences, because gases vary in density with temperature changes.

c. Temperature Differential.

(1) The temperature differential in the atmosphere which causes atmospheric circulation can be compared to the temperature differences produced in

a pan of water placed over a Bunsen burner. As the water is heated over the flame, it expands and its density is lowered. This reduction in density causes the water to rise to the top of the pan; as it rises, it cools and proceeds to the edges of the pan. Upon reaching the edges of the pan, it cools further and sinks to the bottom, eventually working its way back to the center of the pan where it started. This process of heating and cooling sets up a simple convective circulation pattern.

(2) Air within the limits of the troposphere may be compared to the water contained in the pan, with the sun acting as a Bunsen burner. The most direct rays of the sun strike the earth near the Equator. The air at the Equator is heated, rises, and flows along the upper extremities of the troposphere toward both poles. Upon reaching the poles, it cools and sinks back toward the earth, where it tends to flow along the surface of the earth back to the Equator where it started (fig 4-1).

4-3. Theoretical Atmospheric Circulation

Simple circulation in the atmosphere would occur as described in paragraph 4-2 above if it were not for the following considerations:

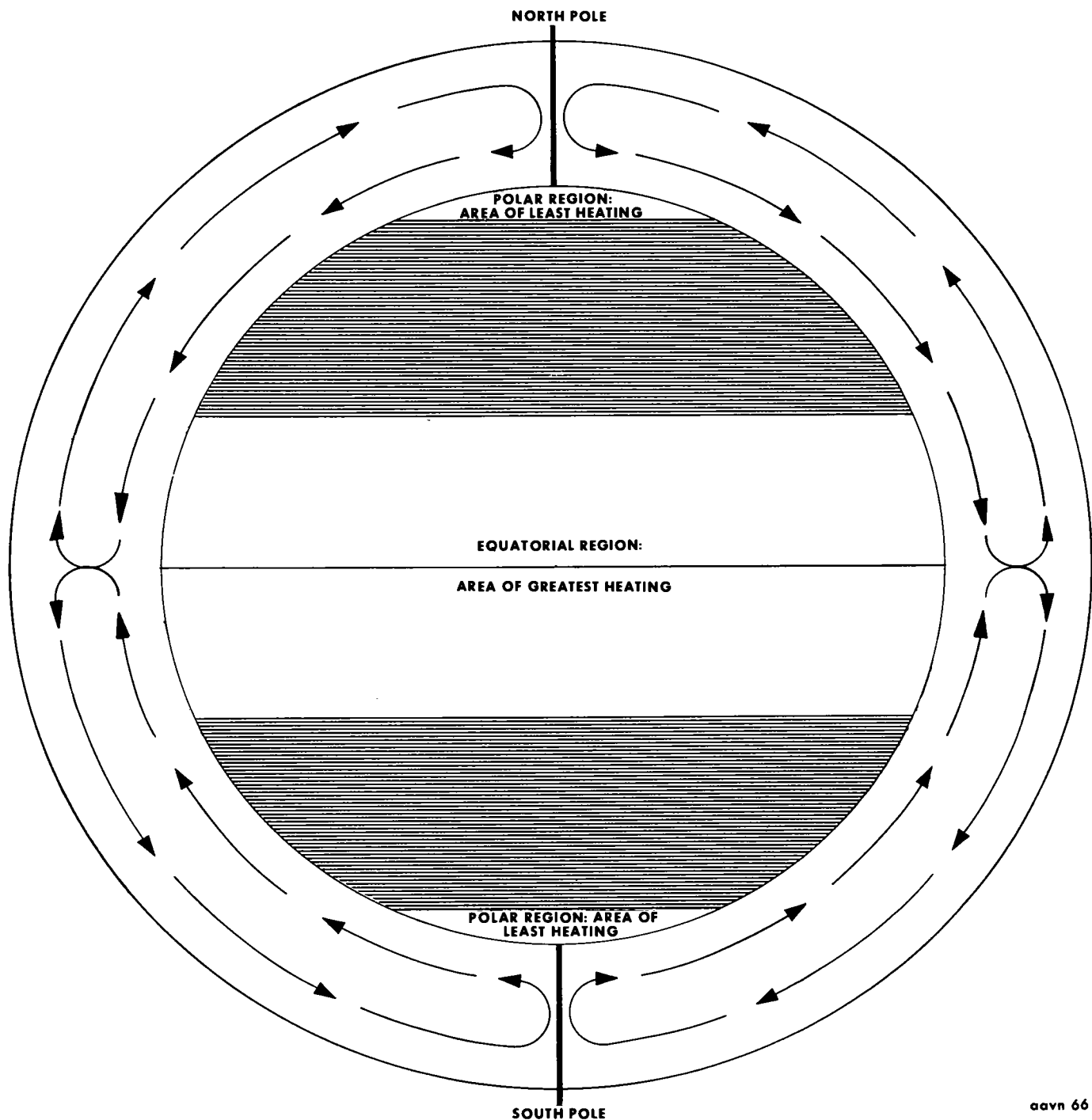
a. The earth is covered with an irregular surface of land and water areas.

b. The earth rotates, so that the area of the atmosphere being heated changes position constantly. *Coriolis deflection* (para 4-8b) further affects the motion of the air on the rotating earth.

c. The tilted axis of the earth causes seasonal changes in the amount of heat received by any specific area of the earth's surface.

4-4. Primary Circulation (Three-Cell Theory)

a. General. According to the *Three-Cell Theory* of atmospheric circulation, the earth is divided into six latitude belts—three in the Northern Hemisphere and three in the Southern Hemisphere. The dividing lines between the six belts are (1) the Equator, (2) latitude 30° N. and S., and (3) latitude 60° N. and S. Thus, there is one belt in each hemisphere between the Equator and 30° latitude, one between 30° and



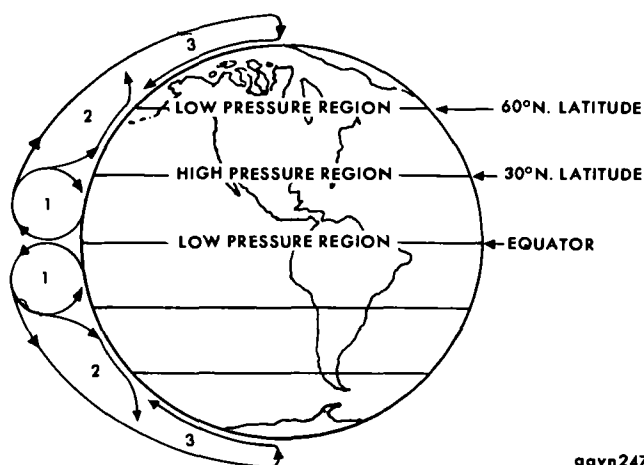
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Figure 4-1. Simple circulation.

60° latitude, and one between 60° latitude and the poles (fig 4-2). This three-cell circulation pattern actually exists in the upper troposphere, but is frequently replaced at the surface by semipermanent cell structures and the secondary circulation of migratory highs and lows. To simplify explanation, further description in (1), (2), and (3) below will be limited to the Northern Hemisphere.

(1) *Equator to 30° Latitude Cell.* The more nearly perpendicular (or more direct) rays of the sun at the

Equator result in greater average heating of the lower levels of the atmosphere. It rises to high altitudes and flows poleward, resulting in a region of low surface pressure at the Equator. This low pressure belt is referred to as the *equatorial trough*. As the air aloft flows northward, Coriolis force deflects it toward the east and causes it to begin piling up over the cool ocean surfaces near latitude 30° N. Some of the air becomes dense enough to descend to the surface around the 30° latitude belt. This descending air is



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Figure 4-2. Three-Cell Theory of circulation.

part of the *subtropical high pressure belt* located between 25° and 35° latitude. Part of the descending air returns to the Equator, thus completing the first cell of the circulation. The air returning to the Equator at the surface is deflected to its right, and becomes a northeast wind called a *trade wind*. The remainder of the descending air at 30° latitude flows poleward at the surface, forming a part of the second cell of the primary circulation:

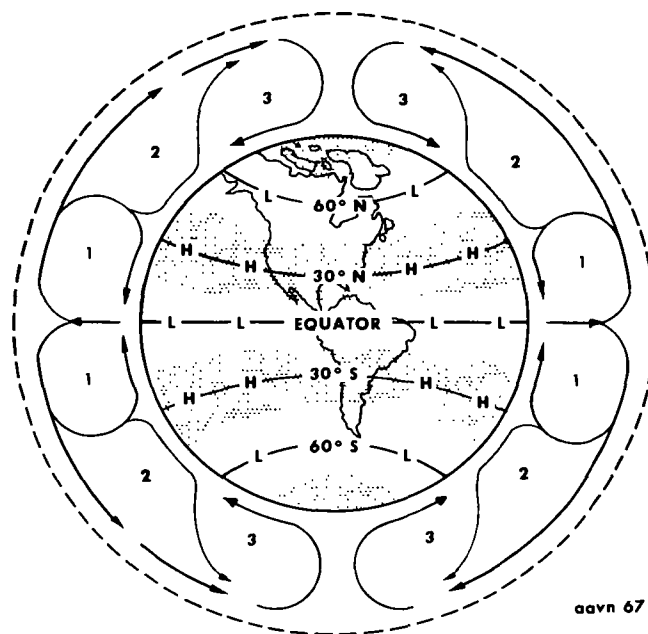
(2) *Cell between 30° and 60° latitudes.* The second cell is composed of poleward-moving air from the Equator in the upper troposphere and from the subtropical high pressure belt at the surface. As this air moves poleward, it is deflected to its right and, in theory, flows from west to east at all altitudes in the troposphere. This cell is known as the belt of prevailing westerlies. These westerly winds are not common at the surface, however, because of the difference in heating between the continents and oceans of the Temperate Zones, and because of migrating pressure systems (para 4-7) in the lower levels of the troposphere. Therefore, these prevailing westerlies are usually upper altitude winds which are responsible for the general movement of the cyclonic storms at the surface from west to east.

(3) *Cell between 60° latitude and the pole.* The third cell of circulation lies between 60° latitude and the pole. Air flowing northward in the upper troposphere spirals northeastward toward the polar region, where it converges aloft and descends. After descending, the air on the cold polar ice cap becomes very dense. This collection of cold dense air produces a region of high pressure at the pole. In theory, the outer limit of this cap of cold air and high pressure is 60° latitude. The belt around 60° latitude is, therefore, a region of relatively low pressure (called the *subpolar low pressure belt*) between the subtropical high pressure areas and the polar high pressure area. In this belt of low pressure, the polar front exists: a

boundary between the cold polar air with its north-easterly winds and the warmer tropical air in the prevailing westerlies. The surface winds in this region are easterlies because air moving from the high pressure center at the poles toward the low pressure area at 60° latitude is deflected to the right of its path and flows from the northeast.

Note. The primary circulation theory of the third cell is not completely realistic in describing the pattern of (a) upper level westerly winds, (b) surface easterly winds, (c) the frontal boundary between the easterly and the westerly winds, and (d) the polar front at the surface in near 60° latitude. In practice, the cold, dense polar air flows southward in large polar outbreaks and runs down across the Temperate Zone, bringing frontal weather and migrating cyclonic storms over the entire region (para 7-7).

b. Southern Hemisphere. The distribution of pressure areas and wind belts in the Southern Hemisphere is the same as in the Northern Hemisphere. However, the Coriolis force in the Southern Hemisphere deflects the wind to the left rather than to the right. The pressure belts in both hemispheres are shown in figure 4-3.



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Figure 4-3. Pressure belts with the three-cell circulation.

4-5. Effects of the Earth's Movement

a. Rotation. As the earth rotates, circulation is affected by the Coriolis force (para 4-9a). The result is that the winds are deflected to the right of their original direction of movement in the Northern Hemisphere and to the left of their original direction of movement in the Southern Hemisphere (fig 4-4).

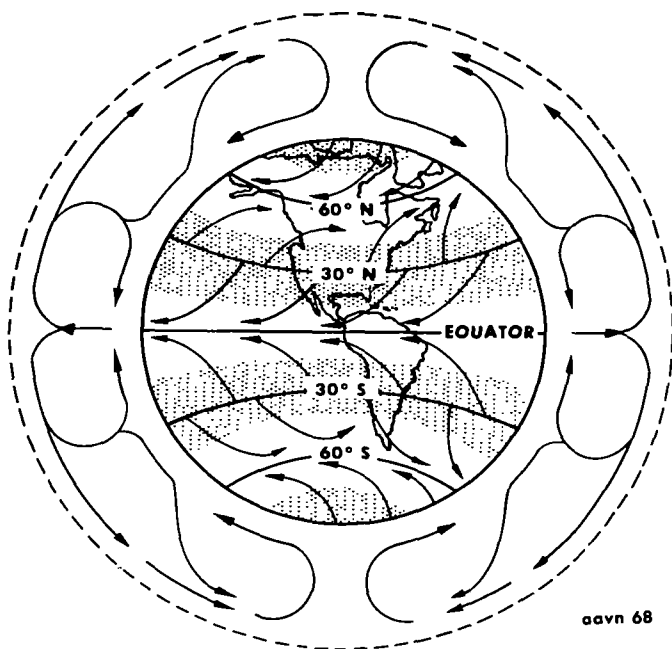


Figure 4-4. Prevailing wind belts with the three-cell circulation.

b. Revolution. The earth's atmospheric circulation is based on a differential in heating. As a result of the seasonal variation in the intensity of the sun's rays on the surface of the earth, areas of differential heating fluctuate in the same geographical location with changes in season. The ideal circulation pattern (fig 4-5) typifies the average position of differential heating areas and assumes a uniform surface of the earth in color, shape, and texture.

4-6. Semipermanent Pressure Areas

a. Large variation in the earth's physical characteristics causes many local surface deviations from the primary circulation pattern discussed above. Friction with the surface of the earth and with great mountain ranges towering up to 5 miles into the atmosphere produces definite changes in the airflow. Another important factor is the difference in specific heats of land and water surfaces. All of these variations from the basic circulation pattern require consideration in any realistic view of the atmospheric circulation in the lower troposphere. The average pressure distri-

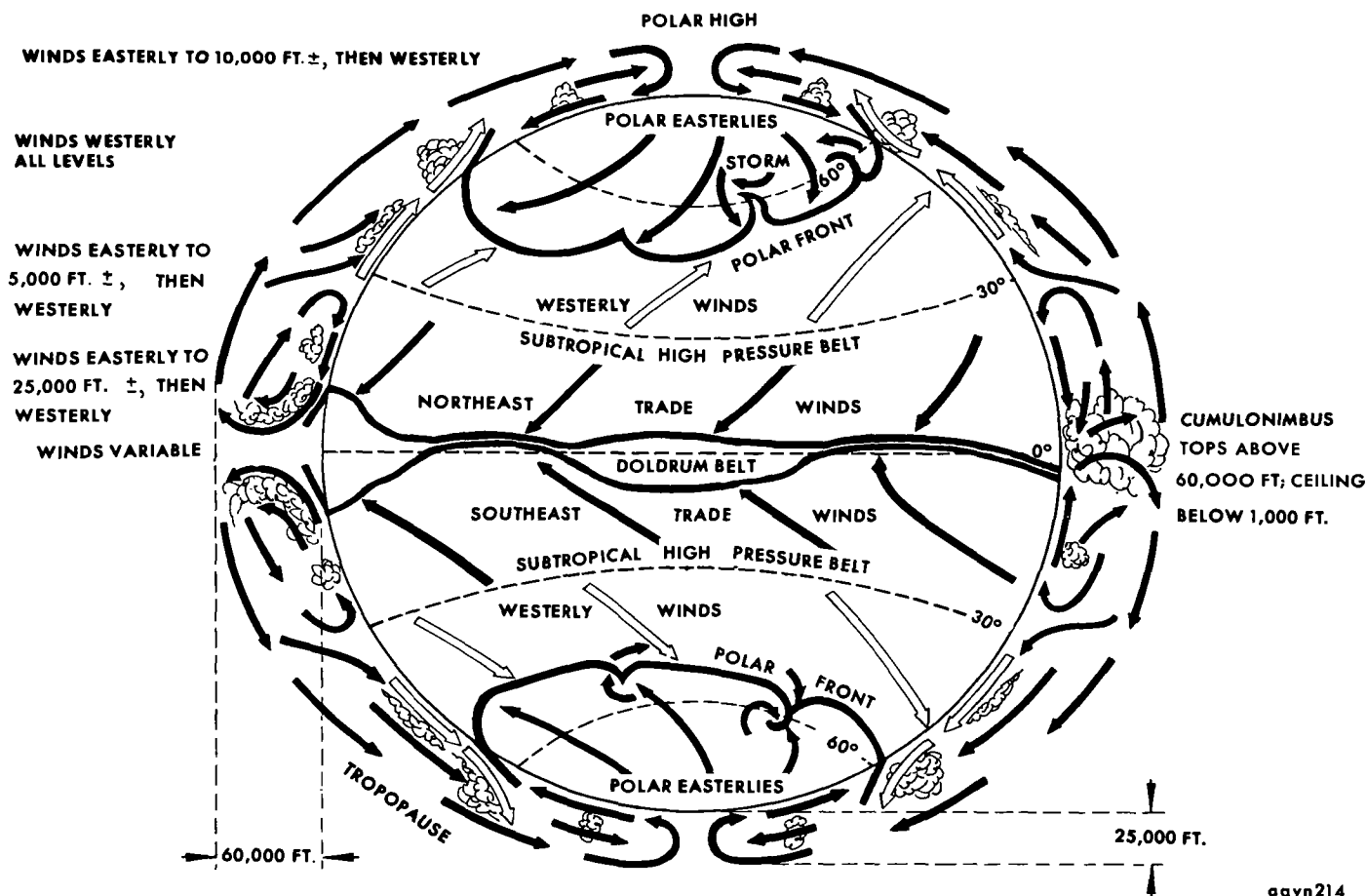


Figure 4-5. Idealized pattern of atmospheric circulation.

bution on the surface of the earth is shown in figure 4-6. The corresponding winter wind patterns over the ocean are shown in figure 4-7.

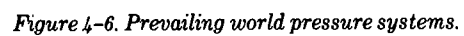
b. Two high pressure cells form in the Northern Hemisphere near 30° north latitude—one over the Pacific Ocean and one over the Atlantic Ocean (fig 4-6). The presence of high pressure over the oceans is in agreement with the general circulation theory of the subtropical high pressure belt; however, over land at this latitude (due to low specific heat of land and its more immediate response to insolation), the theory breaks down and seasonal pressure changes occur.

c. Between the latitudes 45° to 60°, two high pressure cells exist over continental areas—one over Canada (the *North American high*), the other over Siberia (the *Siberian high*). In the summer, because of long hours of daylight (insolation) in northern regions and because the area of the thermal equator will have

moved north of the Equator, these high pressure cells retreat to a more localized position near the pole and become less intense.

d. Two low pressure cells form in the Northern Hemisphere over the ocean near the Aleutian Islands and Iceland. The *Aleutian low* and *Icelandic low* are more intense during the winter season, and verify the location of the polar front with its associated low pressure in the vicinity of 60° latitude. In this area, the warmer air of the prevailing westerlies (northern portion of the subtropical highs) is forced to ascend over the colder dense air of the continental highs.

e. The six semipermanent pressure systems important in the origination and movement of air masses and frontal systems are—Siberian, Pacific, North American, and Bermuda high pressure areas; and the Icelandic and Aleutian low pressure areas.



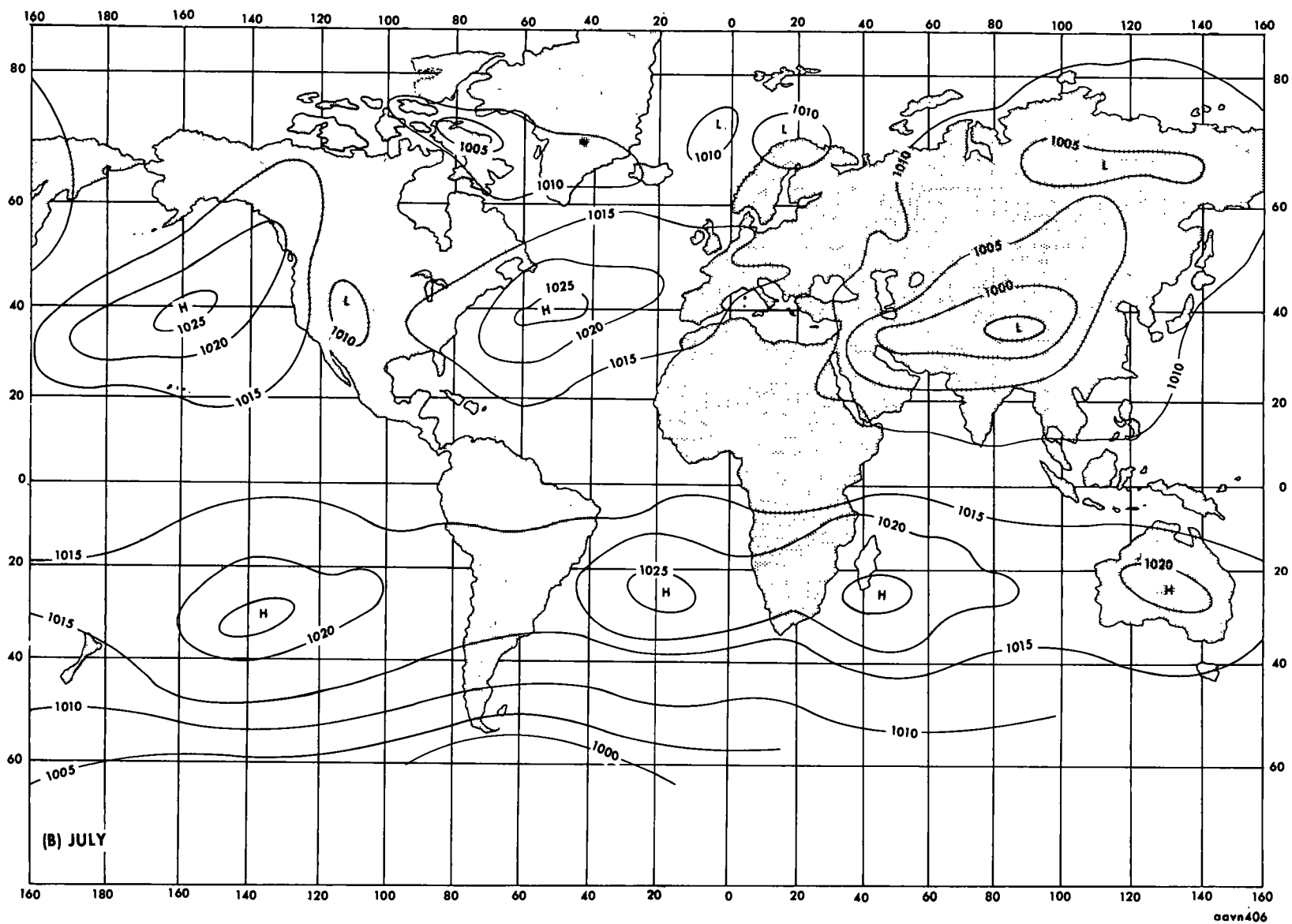


Figure 4-6—Continued.

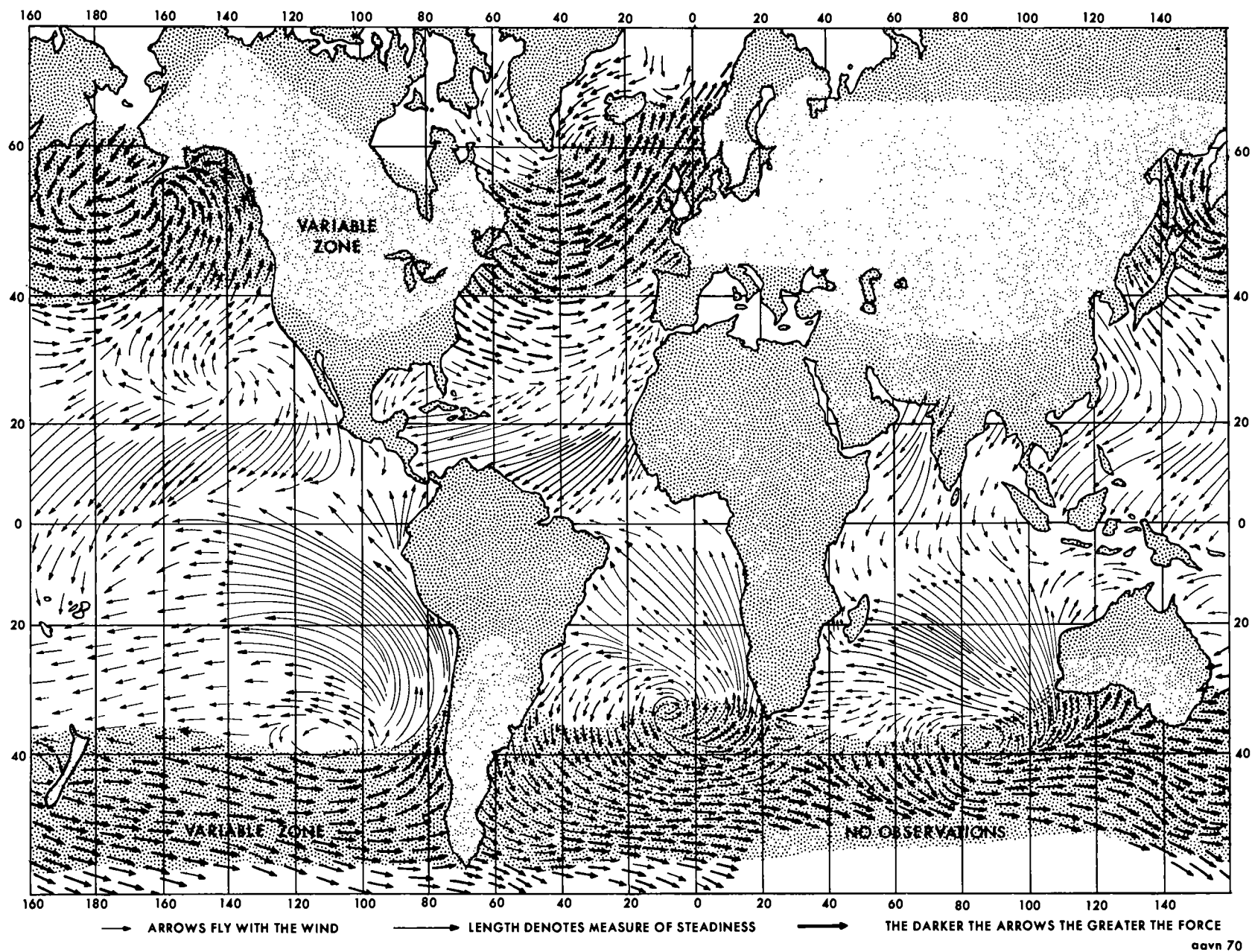


Figure 4-7. January and February world wind system over oceans.

Section II. SECONDARY CIRCULATION

4-7. General

The secondary circulation consists of a series of atmospheric disturbances and irregularities in the lower levels of the troposphere. It is brought about mainly by the movement of high and low pressure systems and the movement of air within the pressure systems. These moving pressure systems are smaller in extent than the semipermanent cells of the general circulation. They are frequently shallow in depth, and move generally from west to east with the prevailing westerly winds above the surface pressure systems. A pressure cell may move 500 miles in 24 hours, with some sections moving more rapidly than others. Some pressure cells remain stationary for several days, whereas others may move eastward at speeds of 50 miles per hour. The moving low pressure systems generally contain fronts, but frontal weather normally is not found within high pressure systems. The complete development of cyclones is explained in paragraph 7-7. The forces which affect the wind in the secondary circulation are discussed in this section.

4-8. Forces Affecting Air Motion

a. Pressure Gradient Force. The intensity of the force acting toward low pressure determines wind speed and is indicated by the spacing between isobars—the *pressure gradient*. The pressure gradient force is the initiating force which produces wind. The closer the isobars, the stronger the pressure gradient. The greater the pressure gradient force, the stronger the wind will be. The pressure gradient force always acts directly across the isobars toward the lower pressure (fig 4-8).

b. Coriolis Force. If the pressure gradient force was the only force affecting wind flow, winds would always flow directly across the isobars from higher to lower pressure. However, the French mathematician, G.G. Coriolis, first demonstrated in 1884 that all non-steered bodies would be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The two aspects of this phenomenon will be explained in general terms and the explanation will be limited to the Northern Hemisphere.

(1) The earth rotates from west to east at a given speed in much the same way that a phonograph record turns on a turntable. Although the revolutions per minute (rpm) are the same, the outward rim of the phonograph record (which, in the case of the earth is the Equator) has more distance to cover over one complete revolution than any of the inner points of the record (which would be comparable to the higher latitudes on earth) and therefore traveling at a faster rate of speed. Our atmosphere is brought along by its gravitational attachment to earth at the same relative

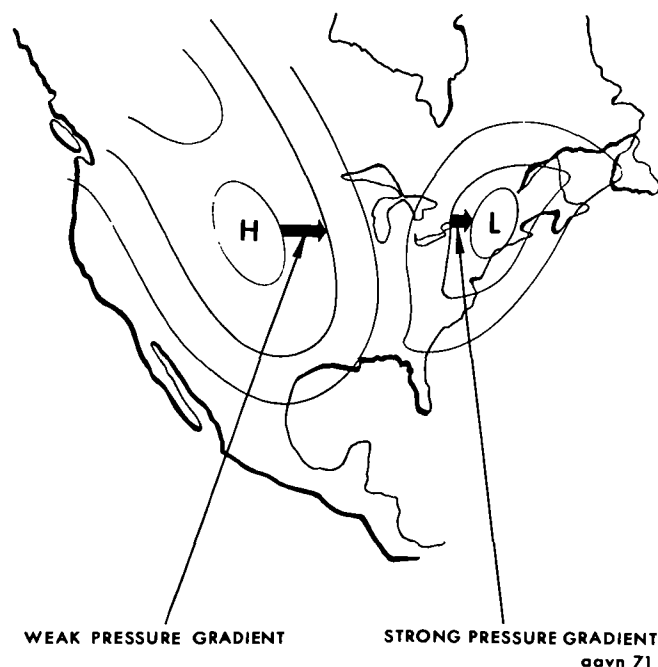
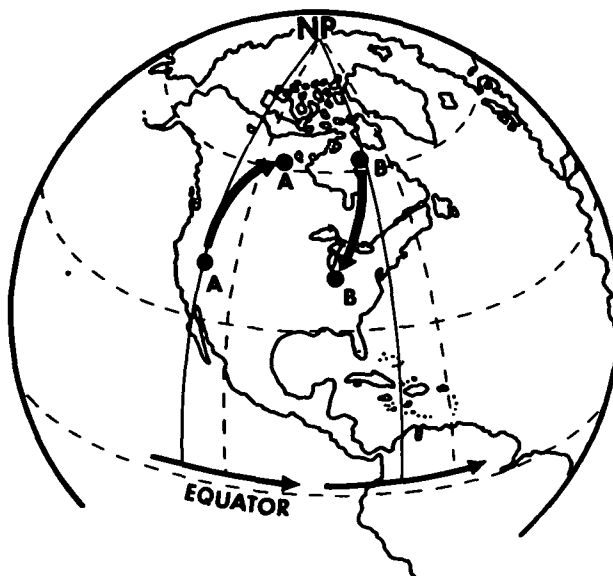


Figure 4-8. Pressure gradient.

speed at each latitude. However, when a migrating pocket of air moves toward another latitude—either northward or southward—a phenomenon takes place known as the *Coriolis force* (fig 4-9). If the pocket of air moves northward, from a latitude with a greater circumference to a latitude with a lesser circumference, it will tend to move ahead (to the right) of the point directly north of its initial starting point because of its greater speed. For a more detailed explanation, refer back to the phonograph record. If the circumference of the record was 2 feet and you fastened a marble at that point and then fastened a marble at a point on the record surface at which the circumference was 1 foot and turned the record one complete revolution, the outside marble would travel twice the distance of the inside marble over the same time period; therefore, its speed would be twice as great. To make up this difference, a free body—such as a pocket of air—must move along an *apparent* curved line ahead of the point immediately opposite its original longitude to obey the law of the conservation of angular momentum. Similarly, a pocket of air moving from north to south, from an area with a smaller circumference to an area with a larger one, would encounter a lag because it is entering a plane with a greater rim speed than the plane it left. Therefore, because of the lag, it too would encounter the effect of a deflection to the right. Thus, a pocket of air either moving northward from the Equator or southward toward the Equator will be deflected toward the right.

As point A tracks north, its original eastward velocity starts exceeding the surface speed and gets ahead of its starting meridian. The effect is a curved track to the right, point A'.



As point B tracks south, its original eastward velocity becomes less than the surface speed and gets behind its starting meridian. The effect is a curved track to the right, point B'.

Figure 4-9. Coriolis force.

(2) The other aspect of the Coriolis force affects the deflection of a parcel of air that is moving east or west. The rotation of the earth (which is the greatest at the Equator) produces a centrifugal force which detracts from the true gravity of the earth and also produces a tendency for the air to accelerate towards and bulge at the Equator. The other factor in this explanation is that the gravitational attraction is greatest at the poles. This is caused by the slightly flattened poles being closer to the center of gravity and also because of the absence of centrifugal force. These two forces, gravity and centrifugal force, tend to neutralize each other as long as the speed of the rotation of the earth is maintained. Without centrifugal force, free moving bodies on the earth would be drawn toward the poles. By the same reasoning, without gravity's poleward component, free moving bodies on the earth would be drawn toward the Equator because of centrifugal force. Therefore, it can be concluded that a body moving from west to east would have an absolute speed equal to its speed plus the rotational speed of the earth. This increased absolute speed of the body would result in an increase in centrifugal force. This would draw the body, in this case a pocket of air, toward the Equator (to the right in the Northern Hemisphere). A free moving body moving in the opposite direction, from east to west, would have an absolute speed equal to the rotational speed of the earth minus its speed. This decreased absolute speed of the body would result in a decrease in centrifugal force. This would draw the body toward the pole or to the right in the Northern Hemisphere.

(3) Combining the two explanations, the following conclusions can be summarized.

(a) The Coriolis deflection is perpendicular to the direction of the flow of air.

(b) The Coriolis force will deflect air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

(c) The Coriolis force is strongest at the poles and decreases to zero at the Equator.

(d) The Coriolis force is zero with calm winds and increases in magnitude as wind speed increases.

(e) Coriolis force, in combination with other forces involved, will determine the different circulation patterns over the earth.

c. Centrifugal Force. Isobars are generally curved around pressure systems. This curvature of isobaric values results in *centrifugal force*. Its influence upon the wind is dependent upon the linear velocity of the air particles and the radius of curvature of the path of the air particles. In the high latitudes, the Coriolis force is of greater significance than centrifugal force, particularly in pressure systems which have a large radius of curvature. Near the Equator, the centrifugal force is of greater importance than the Coriolis force (which is negligible), especially in the case of pressure systems with small radii. In all cases, winds produced by a combination of the pressure gradient force, Coriolis force, and centrifugal force flow parallel to the curved isobars.

d. Frictional Force. Friction tends to retard air movement. Since Coriolis force varies with the speed of the wind, a reduction in the wind speed by friction means a reduction of the Coriolis force. This results in a momentary disruption of the balance. When the new balance (including friction) is reached, the air flows at an angle across the isobars from high pressure to low pressure. This angle varies from 10° over the ocean to more than 45° over rugged terrain. Frictional effects on the air are greatest near the ground, but the effects are also carried aloft by turbu-

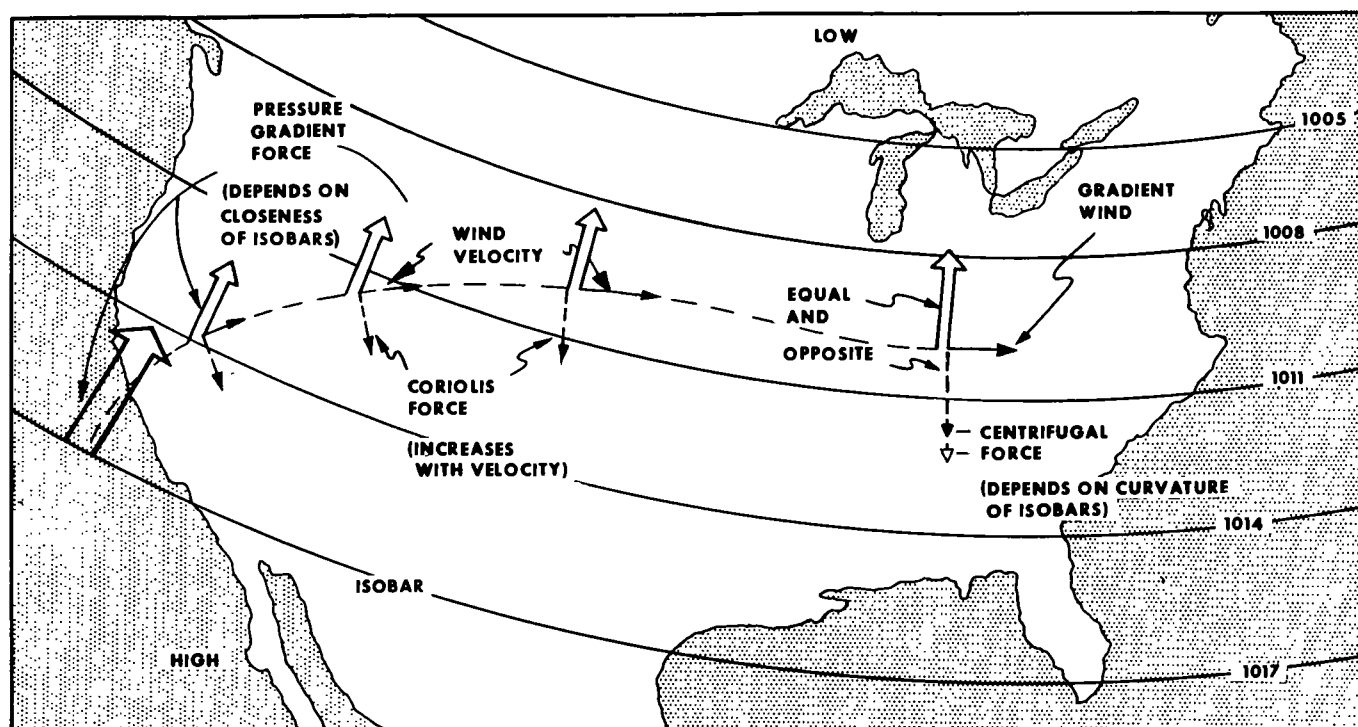


Figure 4-10. Gradient wind.

lence. Surface friction is effective in slowing the wind to an average altitude of 2,000 feet above the ground. Above this level, the effect of friction decreases rapidly and may be considered negligible. Air about 2,000 feet above the ground normally flows parallel to the isobars.

4-9. Wind Systems

a. Winds Aloft.

(1) *Gradient wind.* Pressure gradients initiate the movement of air. As soon as the air acquires velocity, the Coriolis force deflects it to the right in the Northern Hemisphere. As the speed of the air along the isobars increases (fig 4-10), the Coriolis force becomes equal and opposite to the pressure gradient force. After a period of time, the air moves directly parallel to the curved isobars if there is no frictional drag with the surface. The air no longer moves toward lower pressure because the pressure gradient force is completely neutralized by the Coriolis force and the centrifugal force. The resultant wind is called the *gradient wind*.

(2) *Geostrophic wind.* Computations of wind velocity on the basis of pressure gradient and Coriolis force are usually based on the assumption that the isobars are straight and that the centrifugal force is zero. Such a wind, blowing parallel to straight isobars, is called the *geostrophic wind* (fig 4-11). For practical purposes, the gradient wind and the geostrophic wind are considered equivalent and can be assumed to exist near and above 2,000 or 3,000 feet.

b. *Surface Winds.* Friction will reduce the surface wind speed to about 40 percent of the velocity of the gradient wind and cause the surface wind to flow across the isobars instead of parallel to them. This is because the Coriolis force and the centrifugal force are governed by the speed of the air particles making up the wind, while pressure force depends only upon the horizontal spacing of the isobars. The forces that were in balance with the pressure gradient aloft are weakened when introduced to the friction layer over the earth: the pressure force becomes the dominant force on the surface, and the resultant surface wind-flow will be somewhat toward the lower pressure.

(1) *The friction layer.* Surface wind is acted upon by pressure gradient force, Coriolis force, and centrifugal force; however, in practice it tends to flow across the isobars from high toward low pressure (right hand side of fig 4-12). This deviation from the gradient wind pattern is caused by friction, which affects the air to approximately 2,000 or 3,000 feet.

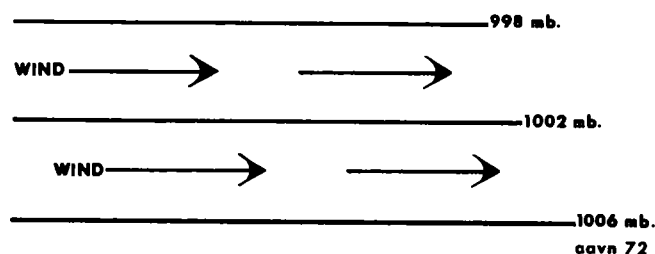


Figure 4-11. Geostrophic wind.

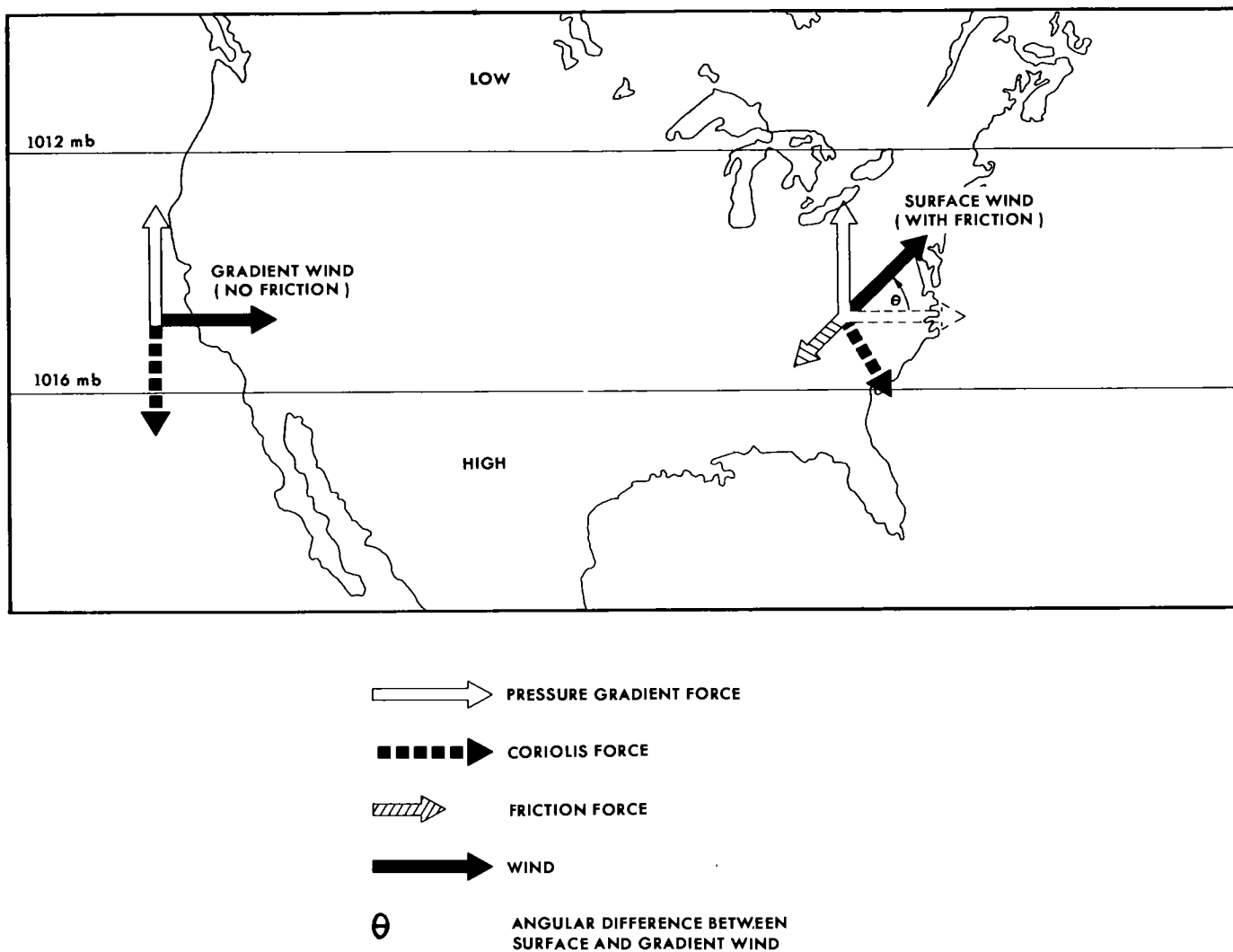


Figure 4-12. Comparison of gradient and surface winds.

The amount of friction depends upon the nature of the surface. It is least over water and greatest over mountainous terrain. The average surface wind will flow across the isobars toward lower pressure at about a 30° angle. The surface friction gradually decreases with altitude until the gradient or geostrophic level is reached.

(2) *Wind versus altitude.* Since the frictional force decreases with altitude, the wind speed will increase in altitude. This increase in wind speed tends to continue above the friction layer up to the tropopause. Beyond the friction layer, increases in wind speed are due to variations in the pressure force with elevation. The normal variations in wind speed and direction with height are shown in figures 4-13 and 4-14.

c. Winds and Pressure Systems.

(1) In the Northern Hemisphere the gradient wind flows parallel to isobars in a clockwise pattern around high pressure centers (anticyclones) and in a counterclockwise pattern around low pressure centers

(cyclones).

(2) Surface winds (fig 4-15) in the Northern Hemisphere flow clockwise around and away from a center of high pressure and counterclockwise around and toward a center of low pressure.

(3) An aviator flying above the friction layer in the Northern Hemisphere with his back to the wind is to the right of an area of low pressure; i.e., with a tailwind, lower pressure is to the left of the aircraft. Similarly, if an aircraft has a tendency to drift off-course to the right, it is crossing the isobars toward an area of lower atmospheric pressure.

(4) The relationship of windflow and pressure systems was discovered by Buys-Ballot in 1857, and is called *Buys-Ballot's Law*.

d. *Convergence and Divergence.* The inflow of air toward a cyclone is called *convergence*; the outflow of air from an anti-cyclone is called *divergence*. Both processes result from the flow of air across the isobars.

(1) The flow of air outward from an anti-cyclone

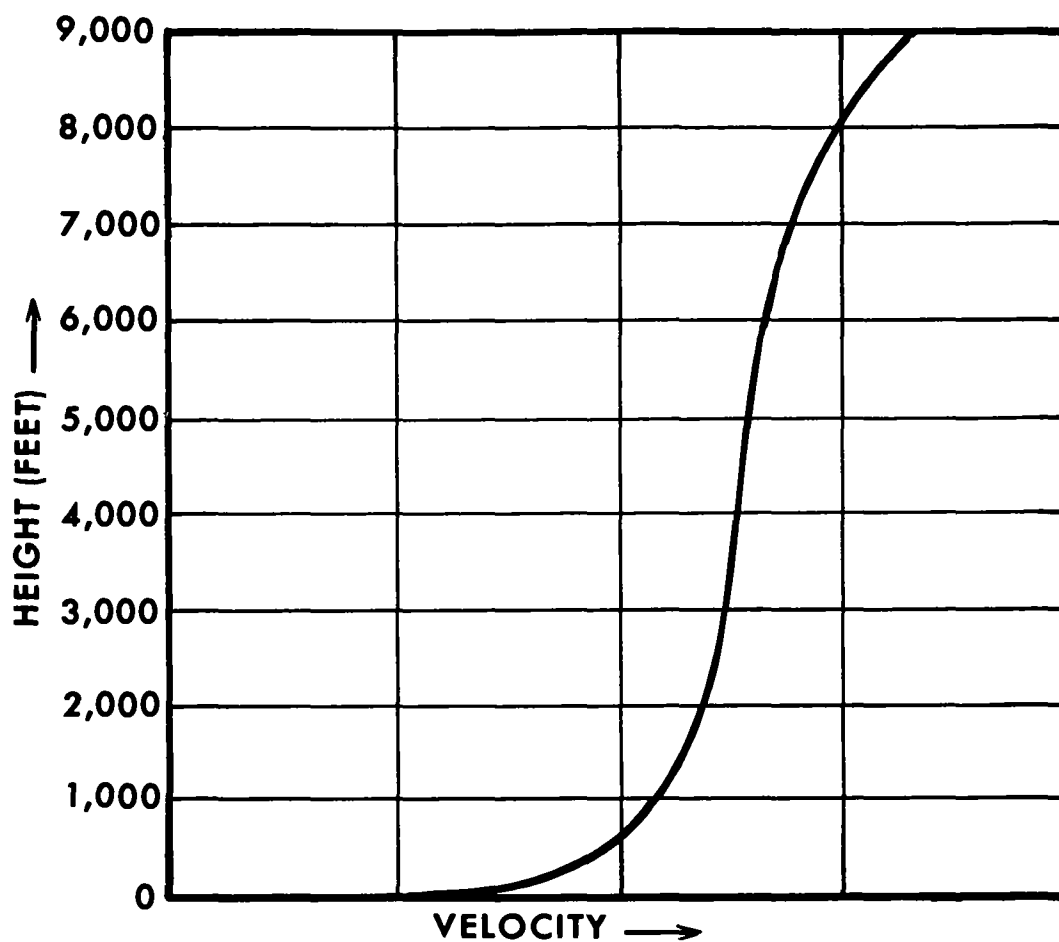


Figure 4-13. Approximate variation of wind velocity with height.

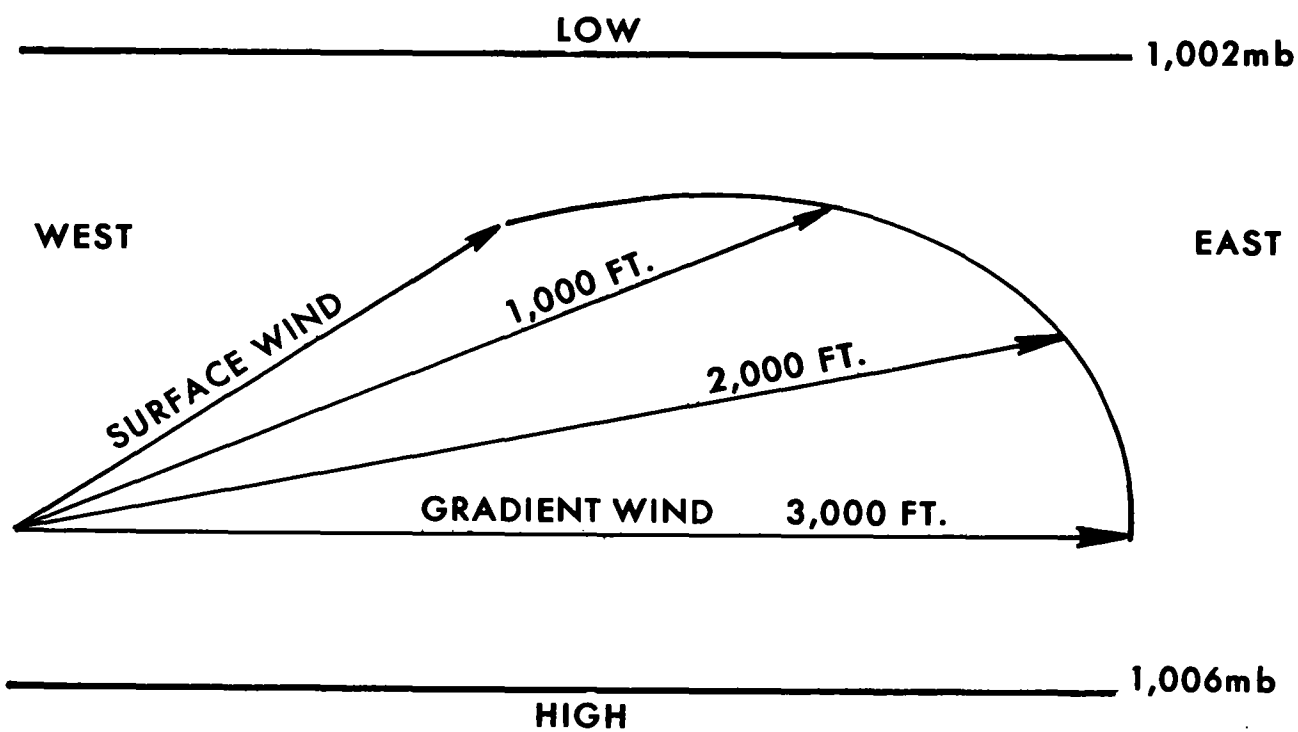


Figure 4-14. Approximate variation of wind direction with height.

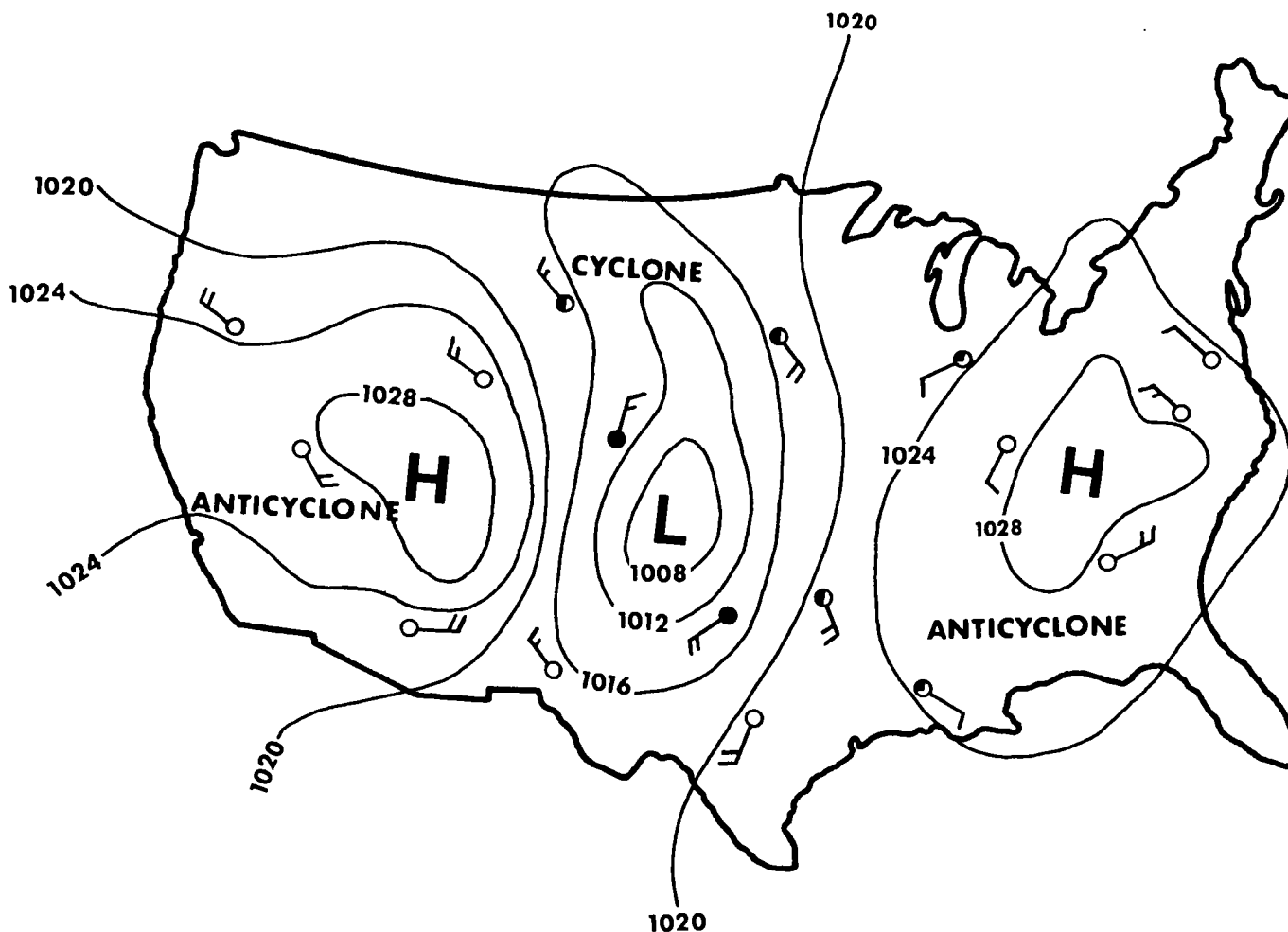


Figure 4-15. Surface windflow in pressure systems.

causes a simultaneous descending action of the air within the high pressure area: this descending process is called *subsidence*. As the air subsides, adiabatic heating (chap 5) decreases the relative humidity and produces generally good weather.

(2) Convergence in low pressure areas forces the air to rise, expand, and cool adiabatically. This cooling increases the relative humidity and produces cloudiness, precipitation, turbulence, strong winds, and generally poor weather.

4-10. Special and Local Secondary Circulations

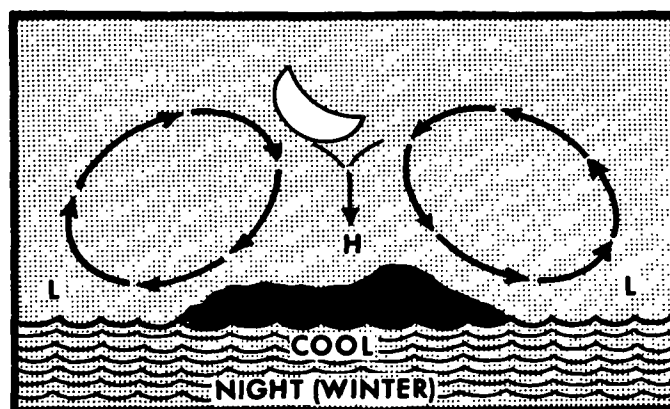
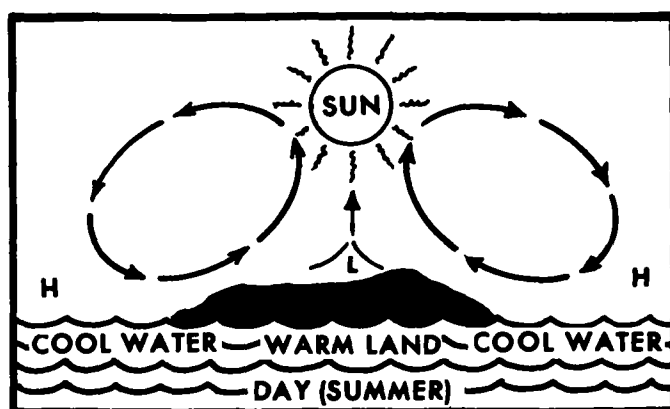
a. Land and Sea Breezes. During daytime, coastal lands generally become warmer than the adjacent water and a lower density will exist in the surface layer of air over land than in the surface layer over the water (fig 4-16). This slight difference in pressure over the land and water surfaces establishes a flow of wind landward (a sea breeze) during the day. The force of the sea breezes depends upon the amount of insolation and terrestrial radiation. Sea breezes are most pronounced on clear days, in the summer, and in low latitudes. Land breezes (from land to sea) occur at

night due to the rapid nocturnal cooling of the land surface. In areas where a well-developed pressure pattern exists, the air will be moving along the isobars with sufficient speed to overcome surface temperature variations in coastal regions. Under these conditions, no land or sea breeze will exist: it will be overpowered by the prevailing winds.

b. Valley and Mountain Breezes. On warm days, winds tend to flow up slopes during the day and down slopes during the night. This is because air in contact with the mountain slopes is warmer than the free atmosphere at the same level during the day and colder during the night. Since cold air tends to sink and warm air tends to rise, a system of winds develops and flows up the mountain side during the day and down during the night. The daytime movement is a valley breeze; the nighttime motion is a mountain breeze.

c. The Monsoon.

(1) *General.* An important factor in the consideration of world weather phenomena is the monsoon and the mechanics of monsoonal circulation. Monsoons are large-scale phenomena which result from



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Figure 4-16. Land-sea effect.

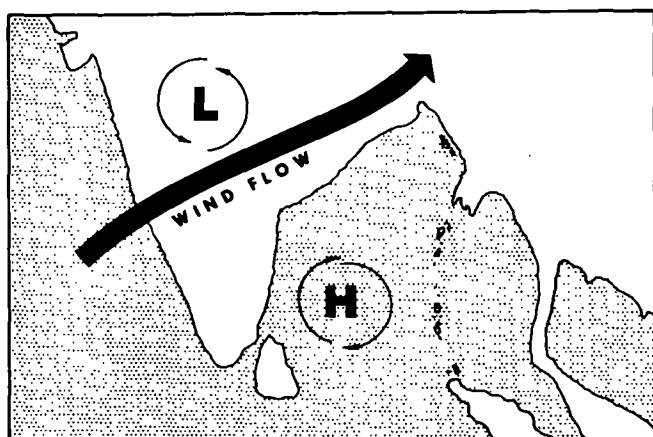
the same heating and cooling processes that cause the smaller scale land and sea breezes.

(2) *Temperatures.* In winter, the land is usually colder than the sea in monsoon areas. This results in an outflow of air from land to sea. In summer the situation is reversed. In large landmass areas (part of which lies near the border of the Tropics and thus gets a large amount of solar heating), the thermal low pressure cells developing in the summer may become so intense that a large-scale flow of moist air from sea to land results. This is the summer monsoon. It is characterized by abnormally persistent winds and large amounts of precipitation as moist maritime air rises up the inland slope of the land mass. Monsoonal circulation is extremely well developed in the India-Burma-China region. The southerly circulation in summer brings the warm moist air to the continent (fig 4-17). The winter pressure pattern causes a flow of very dry air from the north (fig 4-18). A similar monsoon circulation is found in North America, but it is not as well developed as the circulation found in Asia.

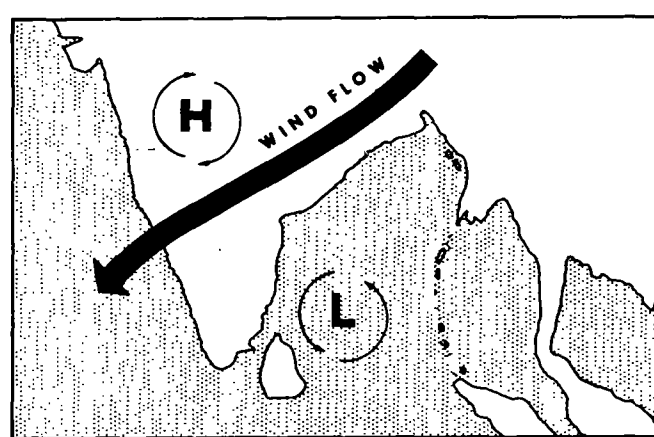
d. The Mountain Wave.

(1) Numerous aircraft accidents have occurred in mountainous areas in strong wind situations, often without a satisfactory explanation at the time. In an effort to make mountain flying safer, a considerable amount of research is underway to gain a better understanding of airflow over mountain barriers. Although much has been learned, present knowledge is far from complete.

(2) First indications of mountain-wave phenomena came from sailplane pilots searching for rising air currents. Gliding and slope-soaring enthusiasts had long taken advantage of the rising air currents on the windward side of a mountain, and had known that generally there is a descending flow on the lee side. However, during the 1930's pilots observed that strong air currents, rising to great heights, were occasionally encountered to the lee of a mountain. Following this discovery, record flights (30,000 feet and higher) were made by using the strong currents of the lee of the Alps. In 1961, an altitude record of 46,267 feet was established in the United States dur-



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Figure 4-17. Summer monsoon.

Figure 4-18. Winter monsoon.



Figure 4-19. Typical cloud formations with mountain wave.

ing a period of strong mountain wave activity to the lee of the Sierra Nevada mountains near Mojave, California. From theoretical studies and firsthand observations by many aviators, a better understanding of the typical mountain wave pattern gradually emerged. It became apparent that the ascending currents were fairly systematic wave patterns rather than random updrafts.

(3) The characteristics of a typical mountain wave are represented in figures 4-19 and 4-20. Figure 4-19 shows the cloud formations normally found with wave development; figure 4-20 illustrates the airflow in a similar situation. These figures demonstrate that

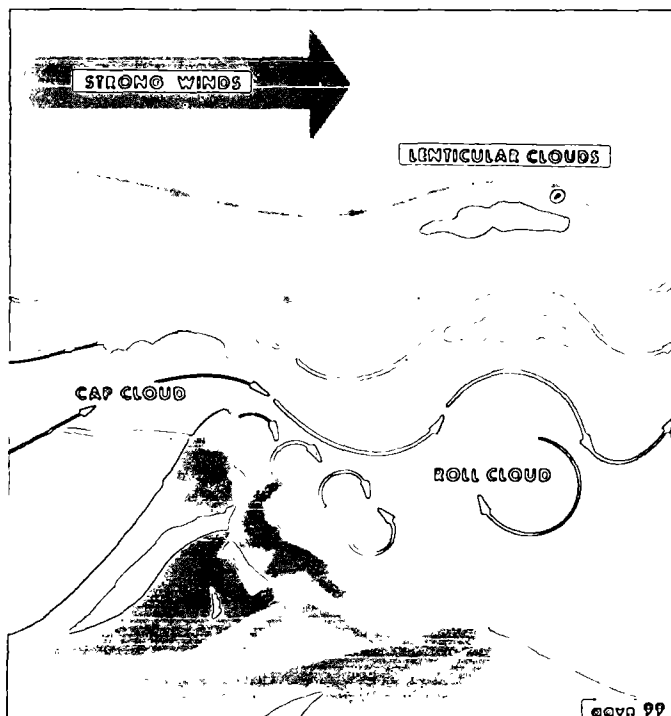


Figure 4-20. Schematic diagram showing airflow in a mountain wave.

the air flows with relative smoothness in its lifting component as the wave current moves along the windward side of the mountain. Wind speed gradually increases, reaching a maximum near the summit. On passing the crest, the flow breaks into a much more complicated pattern, with downdrafts predominating.

(a) An indication of the possible intensities in the mountain wave is reflected in verified records of sustained downdrafts (and also updrafts) of at least 3,000 feet per minute.

(b) Turbulence in varying degrees can be expected (fig 4-20), with particularly severe turbulence in the lower levels.

(c) Proceeding downwind 5 to 10 miles from the summit, the airflow begins to ascend as part of a definite wave pattern. Additional waves, generally less intense than the primary wave, may form downwind. This event is much like the series of ripples that form downstream from a rock submerged in a swiftly flowing river.

(d) Manifestations of three waves can be seen in figure 4-21. The Army aviator is mainly concerned with the first wave, because of its more intense action and its proximity to the high mountain terrain. The distance between successive waves (wave length) usually ranges from 2 to 10 miles, largely depending on the existing wind speed and atmospheric stability, although waves up to 20 miles apart have been reported.

(4) The Army aviator should know how to identify a wave situation and how to plan his flight to avoid wave hazards. Characteristic cloud forms peculiar to wave action provide the best means of visual identification.

(a) The lenticular (lens shaped) clouds in the upper right of figure 4-19 are smooth in contour. These clouds may occur alone or in layers at heights above 20,000 feet (MSL), and may be quite ragged when the airflow at that level is turbulent. The roll cloud forms at a lower level, generally near the height of the mountain ridge, and can be seen extending across the center of figure 4-19. The cap cloud, shown partially covering the mountain slope on the left in figure 4-19, must always be avoided in flight because of turbulence, concealed mountain peaks, and strong downdrafts on the lee slope. The lenticulars, like the roll clouds and cap cloud, are stationary. They are constantly forming on the windward side and dissipating on the lee side of the mountain wave.

(b) The cloud forms are generally a good guide to the degree of turbulence; i.e., smooth airflow occurs in and near smooth clouds and turbulent conditions occur where clouds are ragged or irregular. Smoother conditions exist at the lenticular level than near the roll clouds (fig 4-19). However, close proximity of smooth and turbulent areas is a characteristic of the mountain wave. Smooth flight conditions at the entry of a wave is no assurance of continued smooth



Figure 4-21. Multiple wave formation to the lee of a mountain range.

conditions. Wave action also may occur when the air is too dry to form clouds. Thus, the aviator may fly into a wave area unexpectedly when clouds are not present to indicate the location of wave activity.

(5) In planning a flight where wave activity is suspected, several indications of wave development and intensity are—

(a) Windflow of about 25 knots or more perpendicular to the mountain range. Wave action rapidly decreases as the winds shift from this direction.

(b) An increase in wind speed with altitude up to and above the mountain-top height. Within limits, wave action becomes more intense with stronger winds. However, very strong winds (over 100 knots in the free air above the ridge) may eliminate smooth waveflow patterns entirely, causing very severe but chaotic turbulence.

(c) For sustained wave action, the air must be stable for a thickness of several thousand feet in the vicinity of the mountain ridge. In unstable air, the inherent irregular vertical motions tend to break up the wave action.

(6) If practicable, avoid flight into the wave area. Suggested *safeguards* for flight into an area of suspected wave conditions are to—

(a) Avoid ragged and irregular-shaped lenticular and roll clouds.

(b) Approach the mountain range at a 45° angle, particularly when flying upwind, so that a quick turn can be made away from the ridge when flight continuation appears impracticable.

(c) Avoid flight into a cloud deck lying on the mountain ridge (*cap cloud*) since it can be expected to contain strong downdrafts, turbulence, and the hazards of instrument flight near mountain level.

(d) Fly clear of the roll cloud to avoid its heavy turbulence and downdrafts.

(e) Be suspicious of all altimeter readings. In a wave condition, the altimeter may indicate more than 1,000 feet higher than actual altitude.

(f) When flying into the wind, use updraft areas to gain a safe altitude for crossing the mountain range. In particular, look for rising currents upwind of the roll cloud and of lenticular altocumulus if these

are near flight level. Since apparent updraft areas can be misleading, care should be used in employing this procedure.

e. Foehn (Chinook) Winds. Foehn winds have a strong downwind component, are dry and warm for the season, and are characteristic of many mountainous regions. Along the eastern slopes of the Rockies, they are known as the *chinook*. When air flows up the side and over a mountain barrier, it undergoes expansion and cools at the *dry adiabatic lapse rate* of 3° C. per 1,000 feet until its temperature has dropped to the dew point (para 2-12b). Condensation then occurs, leading to the formation of clouds on the windward side of the mountains. As the air containing clouds rises to the top of the range, the rate of cooling is reduced by the latent heat of condensation given to the air, so that the air temperature decreases on the average of 1.5° C. per 1,000 feet. Through the course of descent on the lee side of the range, warming (caused by compression) of the air takes place at the dry adiabatic lapse rate of 3° C. per 1,000 feet. Thus, during ascent the air gains heat and, having lost its moisture, arrives on the plains beyond the mountain as a dry, warm wind. For example, if a mass of air with a temperature of 68° F. and a relative humidity of 60 percent is lifted over a 10,000-foot mountain, it will arrive at the base on the lee side as a dry air mass with a temperature of approximately 86° F. The Foehn wind may greatly modify cold winter weather, and has an almost magical power to melt snow and ice.

f. Fall Winds (Katabatic Winds). Not all descending air produces a wind that is warm. Where a very cold inland plateau is adjacent to a coastal region, the force of gravity may cause the dense air to drain for several days into the surrounding lower elevations. These gravity winds heat adiabatically as they descend but are still extremely cold. Such cold winds are called *fall winds* or *katabatic winds*. They are usually rather shallow, but wind velocities over 100 knots may occur. Two examples of a fall wind are the Bora of the Adriatic coast and the Mistral of the northwest coast of the Mediterranean Sea.

g. Tornado and Waterspout.

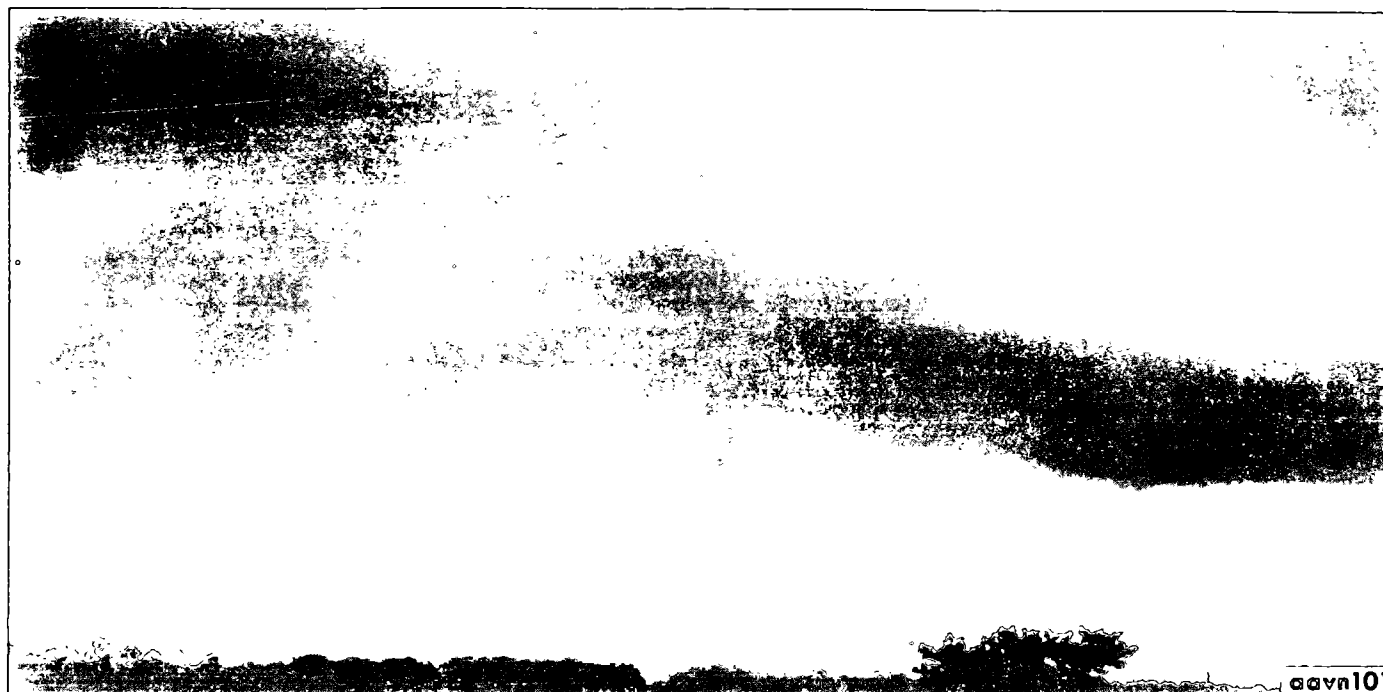


Figure 4-22. Funnel of tornado.

(1) *Tornado.* The tornado (fig 4-22) is the most violent of all storms. It is a whirlpool of air with a varying diameter averaging 250 yards. It is generally associated with severe squall-line conditions (lines of thunderstorms) and is most frequently found in the southeastern quadrant of a well-developed cyclone and the northeastern quadrant of hurricanes. Within the tornado's funnel-shaped cloud, wind speeds are estimated to be from 100 to more than 400 knots, but the forward speed of the tornado averages only 40 knots. Not only is the tornado small in area, but usually it dissipates its energy in less than an hour; its average life is less than 15 minutes.

(2) *Waterspout.* The waterspout is normally a tornado that occurs over the ocean. It contains much moisture; whereas, the continental tornado is laden with dust and debris from the land surface. Waterspouts are also associated with thunderstorm activity or extreme atmospheric instability. The waterspout in figure 4-23 is a rare phenomena composed of two funnels merged near the ocean.

h. Eddy Winds. When air near the surface flows over obstructions such as irregular terrain and buildings, the normal horizontal airflow is disrupted and transformed into a complicated pattern of mechanical turbulence called *eddies* (air currents). The size of the eddies varies with the wind velocity, the roughness of the terrain, and the stability of the air.

(1) With low wind speeds (less than 10 knots), small stationary eddies from 10 to 50 feet in depth are produced on both the windward and leeward sides of the obstructions. Wind speeds between 10 and 20 knots usually produce currents several hundred feet in depth. With stronger wind speeds (20 knots or greater), larger currents form, usually on the lee side

of the obstructions. These larger currents may be carried by the wind for considerable distances beyond the obstruction.

(2) The amount and extent of currents are affected by the roughness of the terrain. Over smooth water surfaces, only a few minor air currents form. In mountainous areas, even though the wind is light, many currents form. Large obstructions to airflow tend to produce more extensive air currents than small obstructions.

(3) When the air is unstable, once currents are formed they continue to grow in height. Such currents may extend to altitudes above 10,000 feet and produce turbulent en route flight conditions.

(4) The variation in wind speed and direction



Figure 4-23. Waterspout.

within the eddies frequently causes considerable difficulty for aviators landing or taking off in small aircraft. The aviator should anticipate eddy winds when operating on fields where large hangars or

similar buildings are located near the runways.

(5) A series of air currents (eddies) may also affect an aircraft taking off or landing in the wake of another aircraft.

Section III. HURRICANES

4-11. General

a. A *hurricane* is a tropical cyclone with winds of 74 miles per hour or greater. They originate over the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico, and the eastern North Pacific along the coasts of Central America and Mexico. In the tropical areas of the western Pacific Ocean, they are called typhoons; in the Indian Ocean and near Australia, they are called cyclones. In general, the hurricane will move in the direction of the prevailing winds of the area. The principal regions and general directions of movement for these storms are shown in figure 4-24.

b. Winds of 74 miles per hour or more are called *hurricane force winds*, regardless of the type storm with which they are associated; but the term "hurricane" is properly applied only to tropical cyclones with winds equal to or greater than this speed. Tropical cyclones with winds less than 74 miles per hour are called *tropical storms* or *tropical disturbances*.

4-12. Causes and Formation

a. Many tropical storms develop from small disturbances carried westward in the easterly trade wind belts. When an area of widespread showers is established, atmospheric pressure in the shower area is usually lower than in surrounding areas; and a gradual inflow of air takes place. Because of the effect of the earth's rotation, the winds, which otherwise would blow directly toward the storm center, are deflected to the right in the Northern Hemisphere. A cyclonic system with counterclockwise winds inclined inward is thus established. When this process takes place over an area of several thousand square miles, it results in a circulation characteristic of a tropical storm.

b. Some of these cyclonic disturbances develop into violent storms within 24 to 36 hours; others reach intensity only after several days; while by far the largest number become no more than mild wind systems with unsettled weather.

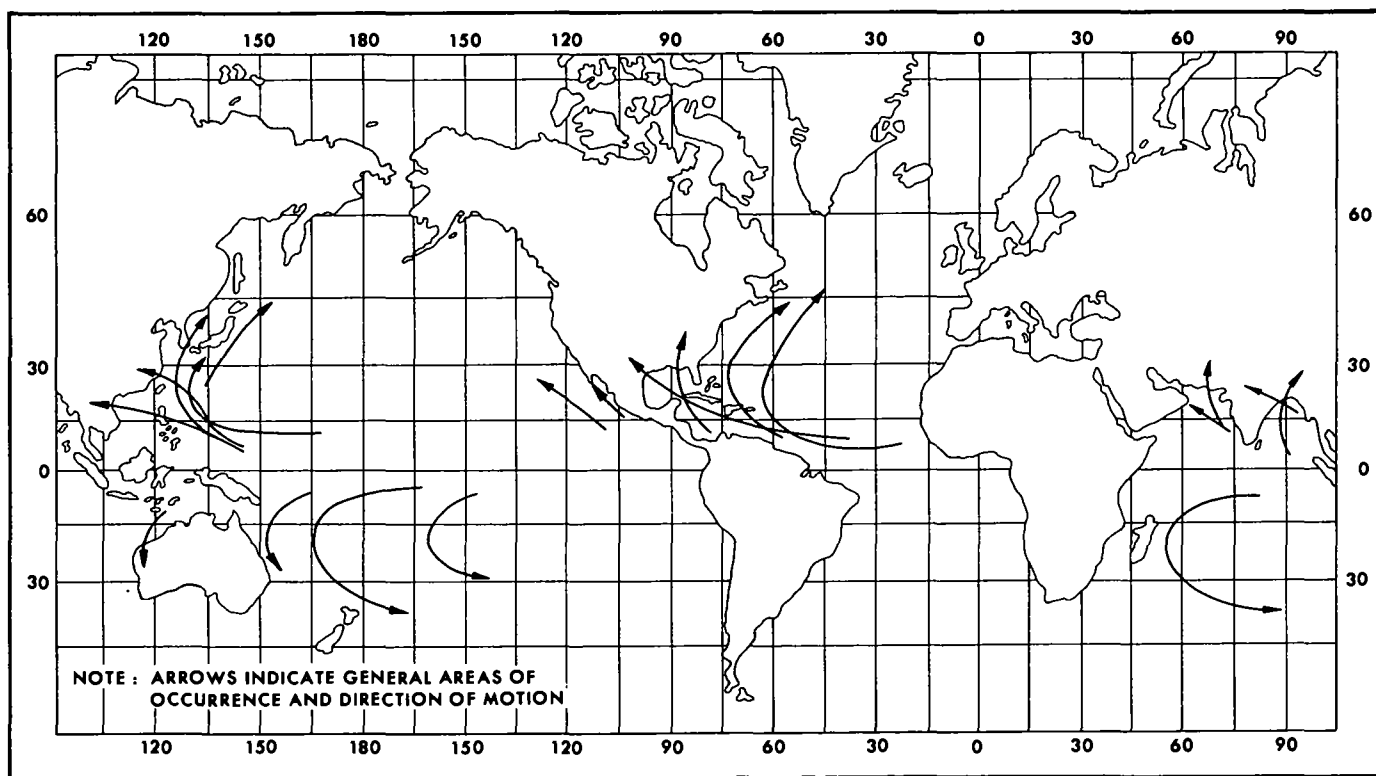


Figure 4-24. Principal world regions of tropical cyclones.

4-13. Motions of Storms

a. At the same time that the cyclonic circulation is established and the winds begin increasing in force, the disturbance, as a whole, also moves. Thus, there are two movements to be considered—(1) the winds directed around and slightly inward toward the center of the cyclone, and (2) the forward movement of the entire counterclockwise wind system. The circulatory movement in the fully developed hurricane is violent, with the speed of the wind near the center sometimes exceeding 150 miles per hour. The progressive movement of the entire system while in the Tropics averages only 12 to 14 miles per hour. This movement usually increases somewhat as the storm approaches higher latitudes, especially after it has recurved to a more northeasterly direction. During the recurving, many tropical storms move very slowly; some remain almost stationary for a day or more. After the recurve (which usually takes place at or a little south of 30° north latitude), the storm generally moves in a direction between north and east, with increasing speed, sometimes at a rate of 40 to 50 miles an hour in higher latitudes. The generally accepted explanation of these movements is that the storms drift with the air currents in which they are imbedded. At the surface of the earth, the general circulation of the winds is from an easterly direction in the Tropics and from a westerly direction in middle and higher latitudes.

b. Storms may come under the influence of disturbances in either the easterly trade winds or the prevailing westerly winds and may alternate between the influence of these two major air currents. Such variable influences may result in a number of loops, abrupt turns, and unusual movements (fig 4-25).

4-14. Center of the Storm

a. The wind system of the hurricane is more or less circular. At the outer limits of the storm, the winds are only moderate breezes with irregular speed and direction. They increase in force toward the center of the storm to a point about 5 to 15 miles from the center of rotation. From this point inward, the winds fall off abruptly. The strongest winds often reach a sustained speed of 75 to 100 miles per hour at the surface, and occasionally even 125 to 150 miles per hour, with gusts of still higher speeds. At the center of a tropical cyclone, there is an area (known as the eye of the storm) with little or no winds. In this central area, the sky sometimes clears so that the sun or stars becomes visible. The temperature usually rises and the air is dry. All around this relative calm is the encircling wall of hurricane winds, which produce a rumbling or roaring sound. The diameter of the relatively calm center averages 15 to 20 miles, but may be less than 7 miles and is rarely more than 30. At sea, the waves

in the eye of the storm commonly are described as mountainous and confused.

b. When the calm center ("eye") of the storm passes over a place, the calm is preceded by winds of great violence from one direction and is followed by violent winds from the opposite direction. If the hurricane approaches from the east, the wind blows first from a northerly direction and, after the passage of the calm center, shifts to a southerly direction. This calm center causes many to believe that the "storm came back"; whereas, it was actually the opposite side of the whirl. Ignorance of the calm-center characteristics has resulted in many injuries and deaths.

4-15. Barometric Pressure

a. In fully developed hurricanes, the barometer nearly always falls below 29 inches (sea level), and there are many records of readings below 28 inches. In the United States, the lowest pressure recorded in a hurricane was 26.85 inches at Bay St. Louis, Mississippi, in August 1969.

b. Changes in barometric pressure and other meteorological conditions observed at San Juan, Puerto Rico, during a hurricane, are shown in figure 4-26.

4-16. Rainfall

The radar picture in figure 4-27 shows the rainfall pattern about a mature hurricane. The white areas in this photograph are areas from which the radar signal was reflected by waterdrops (rainfall) present in the air. Figure 4-28 shows a satellite picture of a hurricane to further show the "spiral band" appearance of the rainfall distributed throughout the storm. Individual convective showers become aligned in this pattern about the center of most well-developed tropical storms. The heaviest rainfall is ordinarily observed in the right semicircle of the storm to the right of the direction of motion of the storm where accumulations have on occasion exceeded 40 inches in a 24-hour period.

4-17. Hurricane Damage

Damage suffered from hurricanes can be inland flooding due to the torrential rains associated with the storm, destruction of property due to violent winds, and the inundation of coastal areas by rises in sea level. The greatest loss of life and property is usually caused by the flooding of coastal areas by abnormally high tides called storm surges. When the storm surges occur at a time of day when the normal tide is high, much more flooding will occur. Hurricanes (including typhoons and cyclones) are the most destructive of all storms. (*Tornadoes consist of much more violent winds, and damage is more severe; but they only affect very small areas compared to hurricanes.*). The diameter of a hurricane may be up to

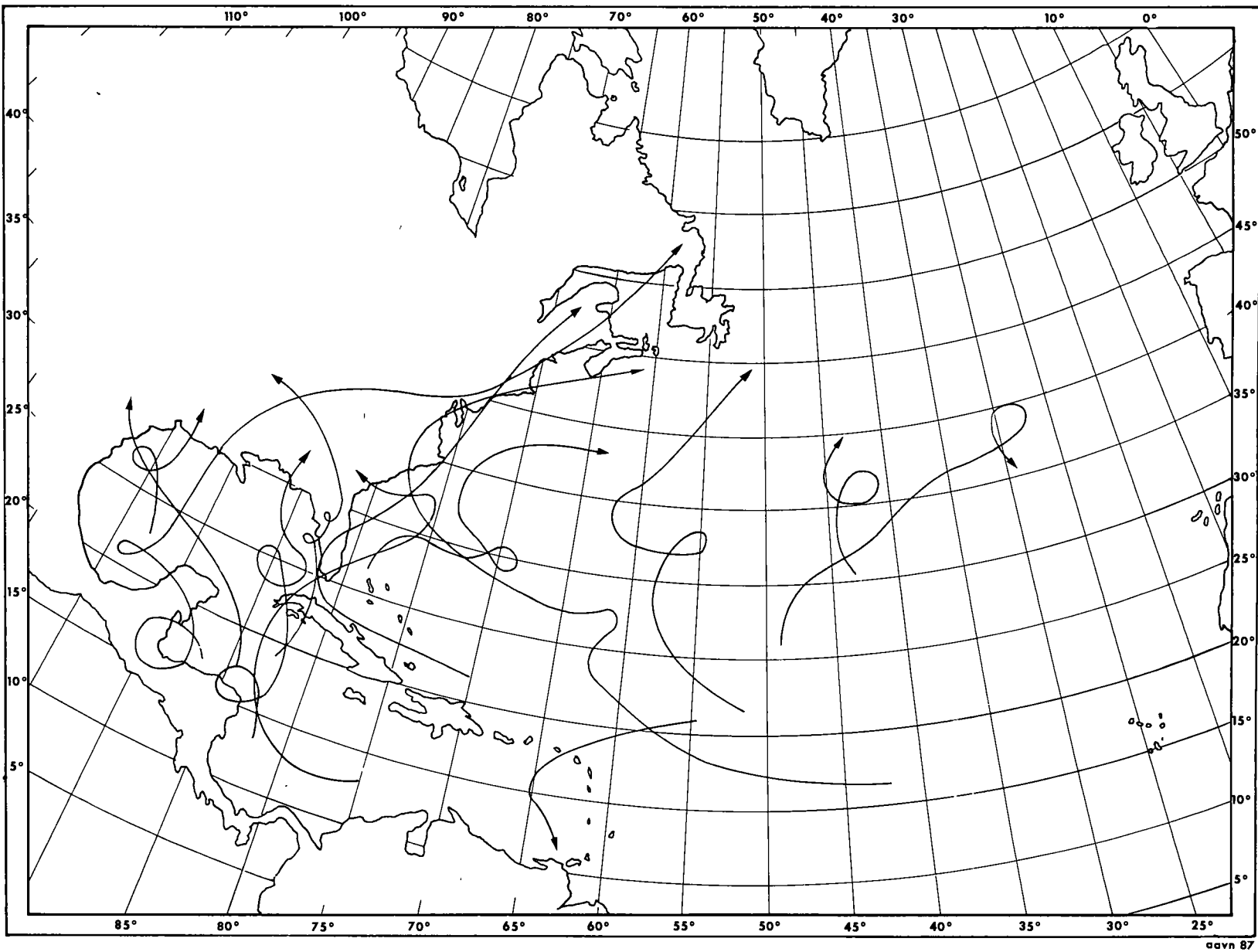
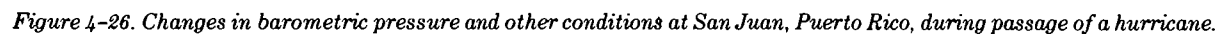


Figure 4-25. Tracks of some tropical storms showing irregular motions.



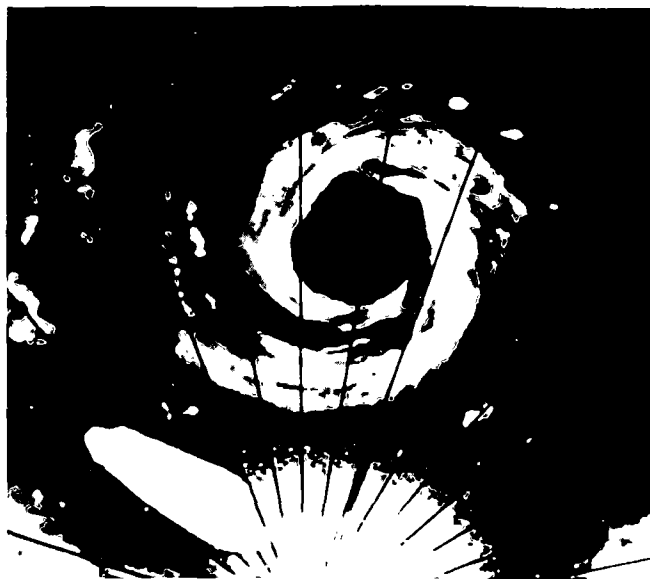


Figure 4-27. Radar scope view of hurricane showing spiral bands of rainfall.

1,000 miles with damaging winds over an area as large as 500 miles. In some small but intense hurricanes, the path of destructive winds may not be wider than 25 miles. Figure 4-29 shows a satellite picture of a typical hurricane for a period of 3 days. An average of about eight tropical storms (including five hurricanes) threatens the conterminous United States each year. Figure 4-30 shows tracks of Atlantic tropical storms for the year 1974.

4-18. Decay of the Storm

It is typical of most hurricanes to decrease in intensity once they move inland. There are three basic factors thought to cause this decay of the storm. First, the lack of moisture input when over land, as a fuel to the storm tends to reduce the energy of the system; second, the cooling of the land surface from the precipitation has a stabilizing effect; and third, the increased surface friction over land acts to retard the windflow.

4-19. Detection and Warning of Tropical Storms

a. Detection. The National Weather Service maintains a constant watch for formation and development of tropical cyclones in the North Atlantic, Gulf of Mexico, west coast of United States, and the North Pacific Ocean. A network of storm warning centers (para 11-3a(3)) using data from long-range weather radar, weather reconnaissance aircraft, ships at sea, and weather satellites continually search for and follow any tropical storm which may develop.

b. Hurricane Warnings. The National Weather Service provides gale warnings and hurricane watch and warning announcements through special weather radios, commercial radio, and television, to alert the general population of impending storms and high seas in coastal regions. Additionally, military installations will have their own unique warning system geared to the needs of their facilities. These warning systems usually consist of a detailed plan of action as to securing property and evacuation of aircraft and personnel as appropriate.

4-20. Flight Hazards of the Tropical Storm

a. All pilots, except those specially trained to explore tropical storms and hurricanes, should avoid these dangerous storms. They contain heavy concentrations of thunderstorms with tops exceeding 40,000 feet. Winds near the center often reach or exceed 150 knots. Although the most severe turbulence is encountered near the "eye," other areas of turbulence exist within the spiral rain bands. Due to the large pressure changes in and near the storm center, altimeter errors can exceed 1,000 feet.

b. For low-level flights circumnavigating the storm, it is preferred to keep the storm to the left of the flightpath to capitalize on the tailwind component. It should be noted that the most intense part of the storm is found in the right front quarter of the storm center relative to its direction of movement. *Most tornadoes which have occurred with hurricanes were located in this quadrant.* The weakest portion of the storm is usually the left rear quarter with respect to the path of movement.

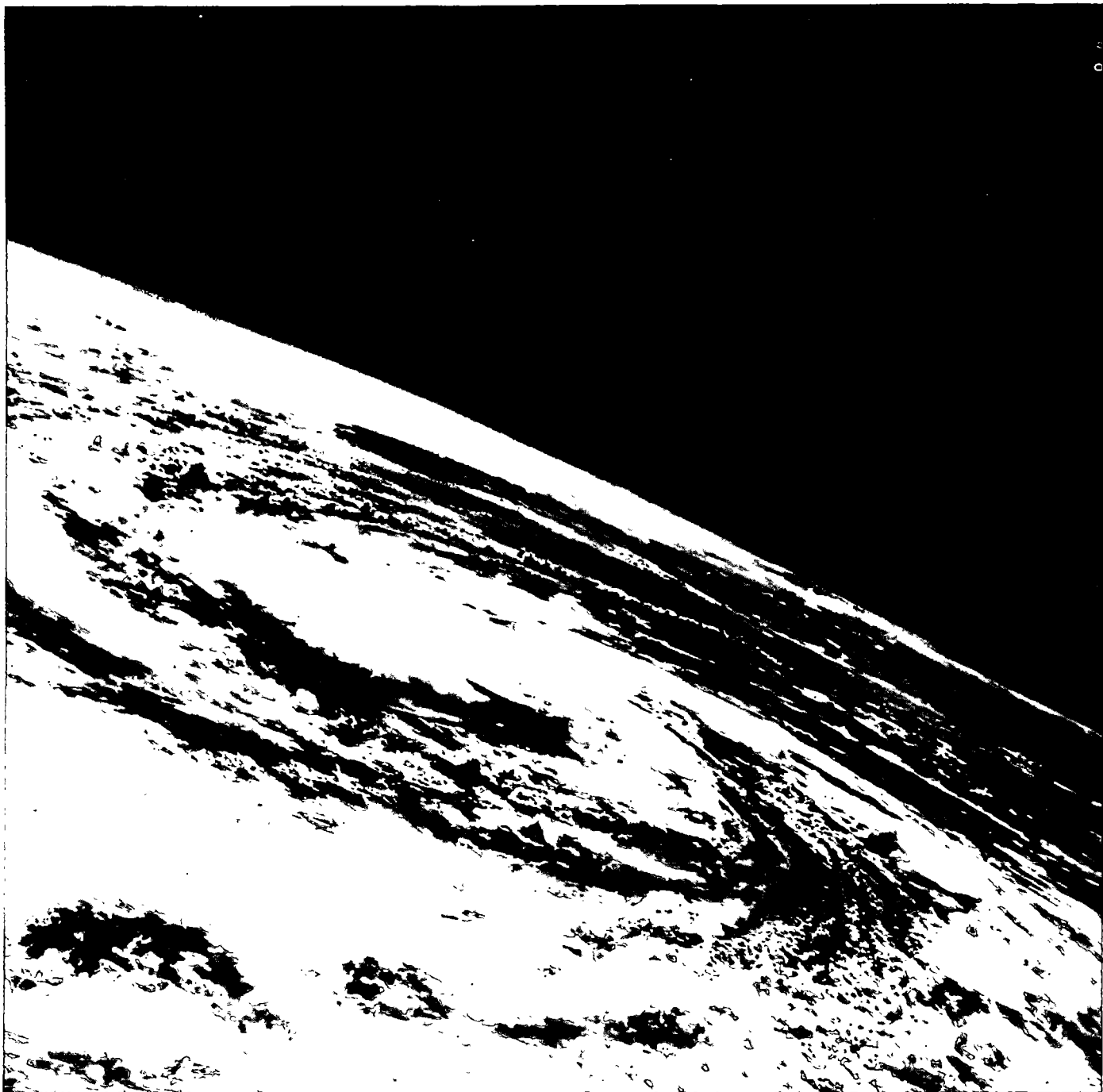


Figure 4-28. Satellite picture of hurricane.

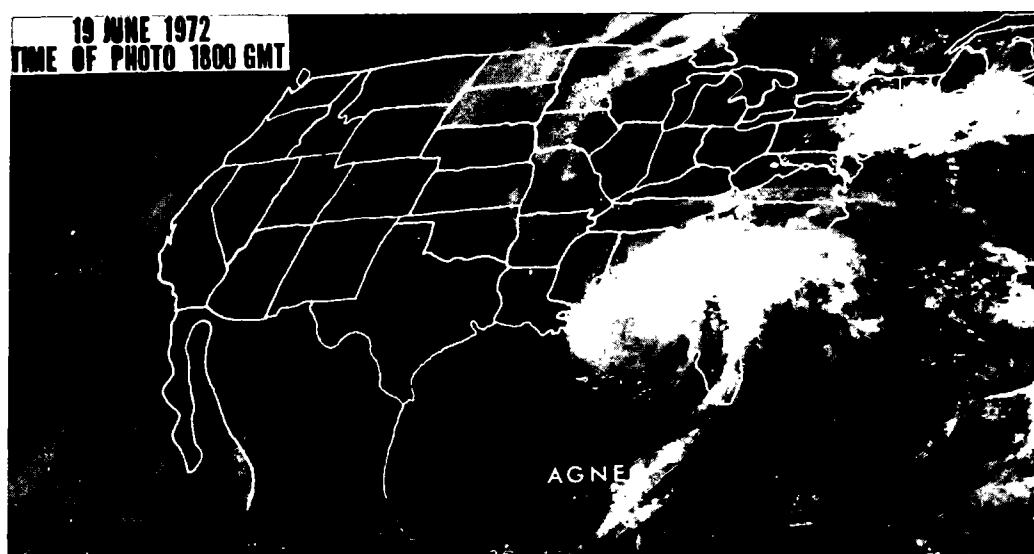
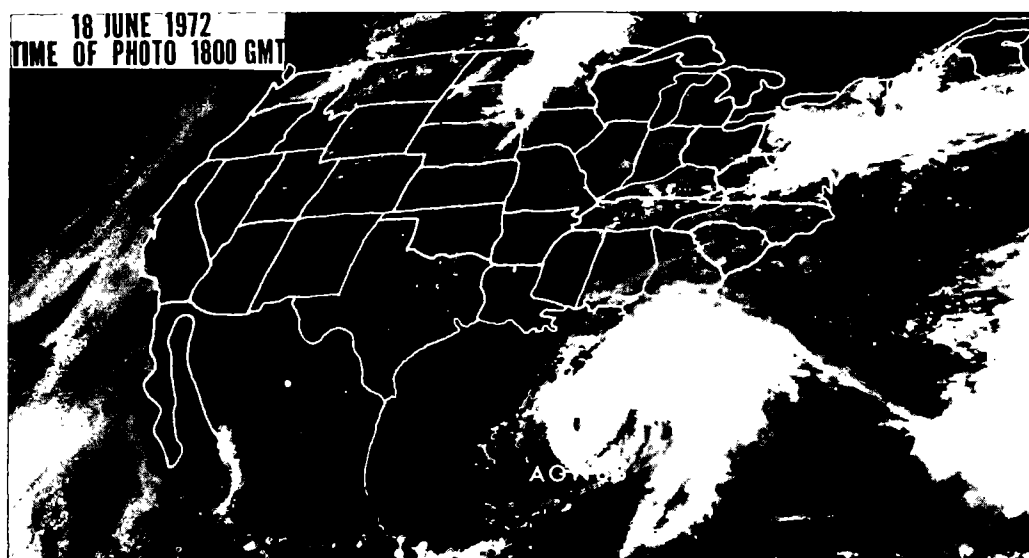
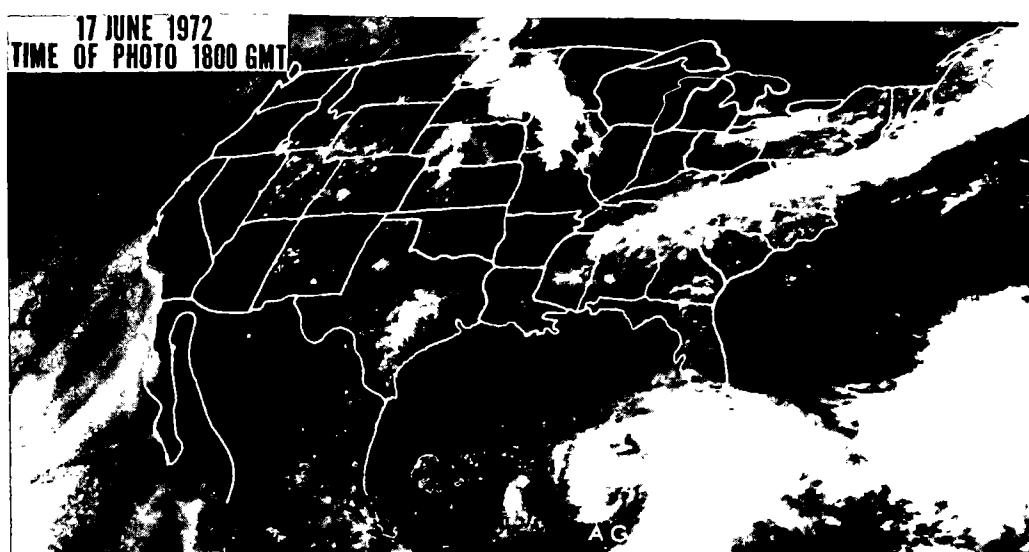


Figure 4-29. Satellite picture of hurricane for a 3-day period.

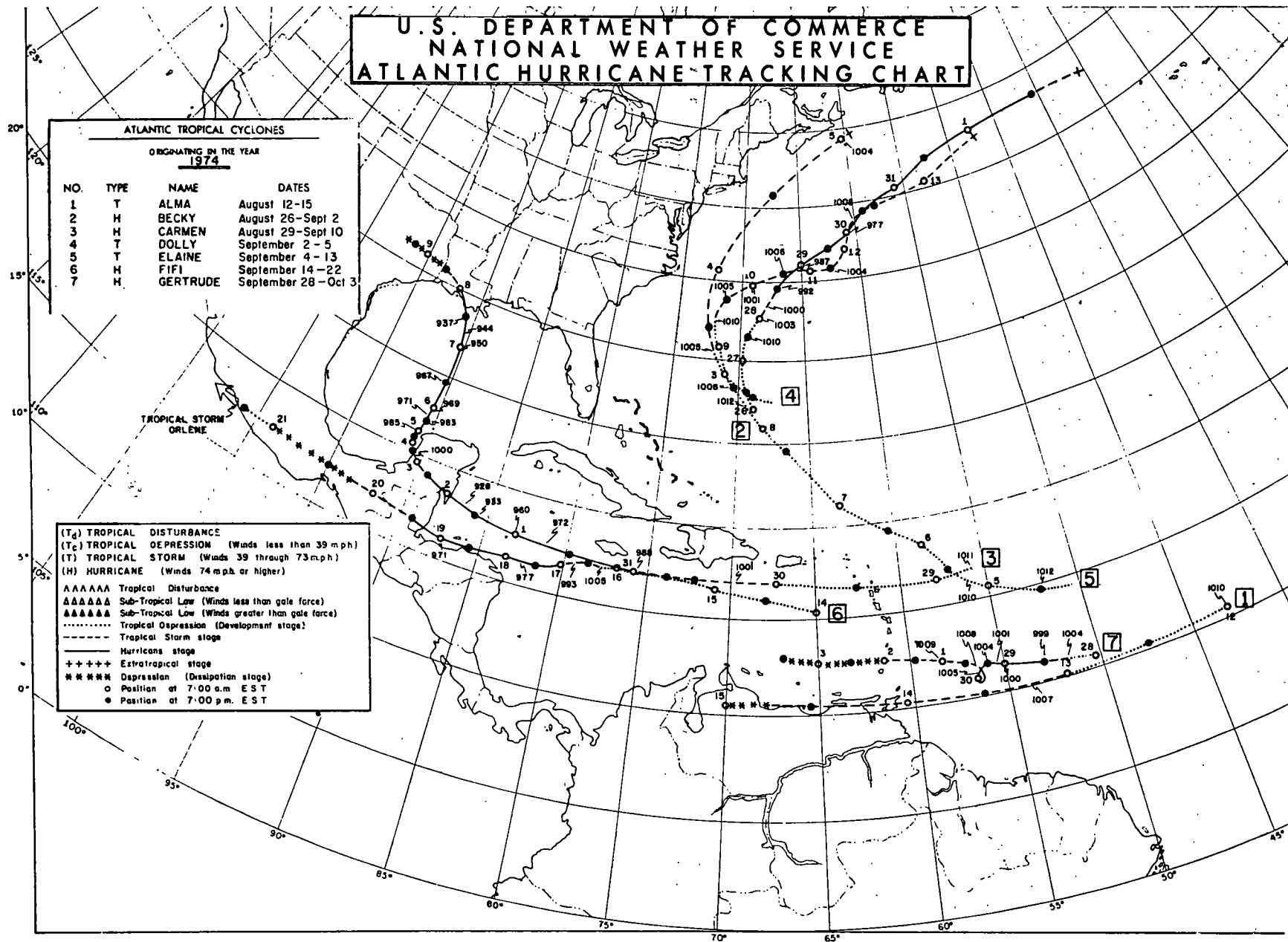


Figure 4-30. Tropical storm tracks for Atlantic in the year 1974.

CHAPTER 5 ATMOSPHERIC STABILITY AND INSTABILITY

Section I. ATMOSPHERIC STABILITY

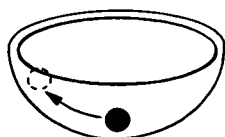
5-1. General

To analyze the atmosphere from data gathered by upper-air soundings (para 5-7), it is necessary to determine the stability of the atmosphere. The temperature lapse rate determines the stability of the atmosphere. Atmospheric stability is comparable to mechanical stability which may be exemplified by using a ball, a round-bottomed bowl, and a table. The ball may be placed in three states of equilibrium—*absolutely stable*, *neutrally stable*, and *absolutely unstable*.

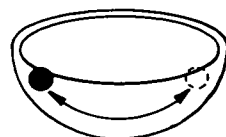
a. Absolute Stability. Set the bowl on the table in its normal position, and place the ball in the bowl (fig 5-1). If the ball is forced to move by some outside influence which is later removed, the ball will, after a series of oscillations, return to its original position. If the ball resists displacement from its original position, it is in a state of absolute stability.



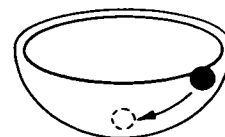
BALL IN BOWL



FORCE MOVES BALL



MOVED BALL OSCILLATES



**BALL EVENTUALLY RETURNS
TO ORIGINAL POSITION**

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Figure 5-1. Absolute stability.

b. Neutral Stability. Place the ball on the table top (fig 5-2). If the ball is forced to move by some outside influence, it will continue to move as long as that influence is present. When the influence is removed, the ball will come to rest. It has no tendency to continue moving away from its original position nor to return to its original position; it is in a state of neutral stability.

c. Absolute Instability. Invert the bowl on the table top, and place the ball on the bottom of the inverted bowl (fig 5-3). If the ball is released when it is in this position, it immediately begins moving away from its original position and does not return. This condition is absolute instability.

5-2. Types of Atmospheric Stability

As used in meteorology, *stability* is atmospheric resistance to vertical motion. For practical purposes, the atmosphere is always in one of three states of stability: it is either *absolutely stable*, *absolutely unstable*, or *conditionally unstable*.

a. Absolutely stable air will resist vertical motion. If it is lifted, it will return to its original level in the atmosphere when the lifting force is removed.

b. Absolutely unstable air will not resist vertical motion. Once a lifting action has set the air in vertical motion, it will continue to rise even when the lifting force is removed.

c. Conditionally unstable air will act like absolutely stable air as long as it is not saturated. Once clouds begin to form, it will, under certain conditions, become unstable. A complete explanation of this process is covered in paragraph 5-5c.

5-3. Lifting Processes

a. Convection. Vertical currents (convection) may be induced by any one of the following processes:

(1) *Thermal convection.* Air which is resting on the earth's surface may be set in motion by surface heating which is most noticeable during the afternoon. Vertical currents may also result when cool air moves over a warm surface and is heated by contact with the warm surface.

(2) *Frontal lifting.* At the boundary of air masses of different densities (a front), the less dense air is lifted. In some cases, this lifting action can be quite rapid; in other cases, the warmer air mass may be lifted quite slowly over the colder air mass. With

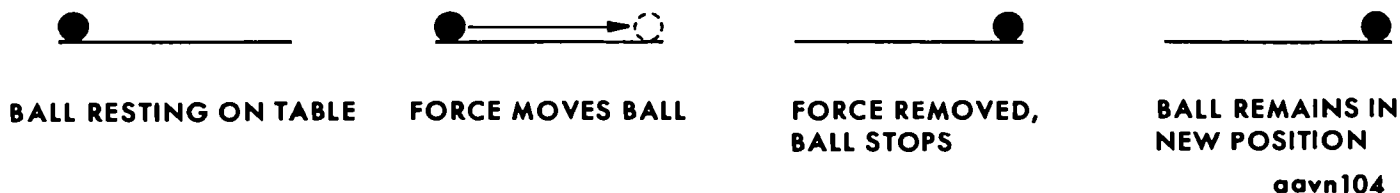


Figure 5-2. Neutral stability.

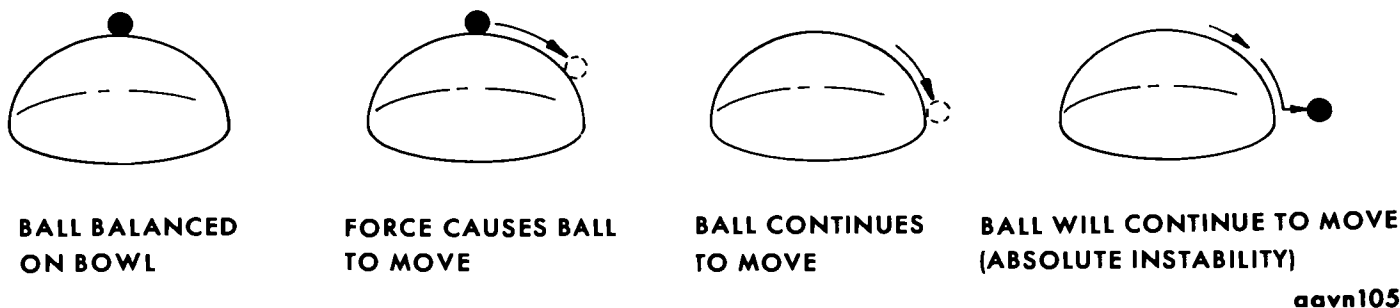


Figure 5-3. Absolute instability.

frontal lifting, large layers of air are lifted several thousand feet over a long and sometimes wide area. This action is the primary cause of all frontal weather (the lifting of warmer air by the colder air mass).

(3) *Mechanical lifting.* Vertical currents (convection) may be caused by two orographic conditions:

(a) Air masses may be frequently forced to rise over hills or mountain barriers. This may cause undesirable weather for many miles along the windward side of the barrier due to upslope winds.

(b) Air masses passing over rough terrain features such as buildings, ridges, gulleys, and similar obstructions will cause turbulence.

(4) *Convergence.* Convergence is the inflow of air into an area. It may result from different wind velocities in relatively straight line flow or from the flow of wind across the isobars at the surface into regions of low barometric pressure. As the air rushes into the cyclonic center from all sides, it rises in great volumes to compensate for the convergent action.

b. Extent of Vertical Currents. Although the air may be forced to rise by any of the forms of lifting action, the stability of the atmosphere governs the height to which the air currents will continue to rise. If the air is stable, the vertical currents will stop a short distance above the upper limit of the lifting action. If the air is unstable, the currents will continue to rise as long as the atmospheric instability exists. These currents may continue up to the tropopause. If the air is conditionally unstable, clouds must form before the currents can continue to rise above the upper limit of the initiating lifting action.

5-4. The Adiabatic Process

As a parcel of air moves upward in the atmosphere, the pressure around the parcel decreases. The rising parcel of air expands as the pressure around it decreases. This expansion allows the air molecules to move farther apart than they were at the surface. They collide less frequently and produce less temperature. When air rises 1,000 feet in the atmosphere, the resultant expansion of the air causes temperature of the air parcel to decrease 3°C . in unsaturated air and approximately 1.5°C . in saturated air. If air descends in the atmosphere, the pressure around it increases and it is compressed. When air expands, it cools; when compressed, it warms. Outside heat energy is neither supplied to nor withdrawn from the air during the expansion or compression. Such a change in temperature, produced solely by a change in pressure, is known as an *adiabatic process*. The constant rate of cooling and heating in the rising or descending parcel of air is known as the *adiabatic lapse rate*. Because air is such a poor conductor of heat, the parcel is thermally insulated as it rises or descends. Changes in adiabatic temperature are independent of those that occur in the atmospheric layer through which the air parcel is rising or descending.

a. The Dry Adiabatic Lapse Rate. As a parcel of unsaturated air moves away from the surface, the adiabatic process produces a temperature change (decrease) of 3°C . per thousand feet of rise. This is called the *dry adiabatic lapse rate*. *Dry*, in this case, does not mean that the air is free of water vapor; it means that no condensation is taking place. The adiabatic lapse rate is unaffected by water vapor in the air because all gases expand at the same rate as the pressure on them decreases.

b. The Moist Adiabatic Lapse Rate. As a parcel of air rises in the atmosphere and cools adiabatically, its ability to maintain moisture in the vapor state decreases. As the temperature lowers, relative humidity increases until the rising parcel of air becomes saturated. At this point, the water vapor begins to condense from gas to liquid. This change of state releases latent heat to the rising parcel of air, so that two processes work simultaneously—(1) cooling from the expansion of the air, and (2) condensation which adds heat energy to the air parcel. The addition of heat reduces the rate of cooling and, as the air continues to rise, the resultant temperature decreases at the rate of approximately 1.5° C. per thousand feet. This new rate of cooling is called the *moist adiabatic lapse rate*. It is used for any rising parcel of air in which clouds are forming.

5-5. Stability and Temperature Lapse Rate

The stability of an atmospheric layer is governed by the temperature lapse rate within the layer. The *ob-*

served lapse rate is the temperature change with altitude which occurs in air that is not moving vertically. The observed lapse rate is usually measured with radiosonde equipment. Over the United States the average rate of temperature decrease with altitude is 2° C. per thousand feet. The actual change in temperature with altitude may vary from an inversion to a decrease of more than 3° C. per thousand feet. The relationship between stability and the temperature lapse rate is illustrated in figures 5-4 through 5-6.

a. Absolute Instability (Fig 5-4). Figure 5-4(A) shows a parcel of unsaturated air at the surface with a temperature of 15° C. The observed lapse rate is 4° C. per thousand feet, being 15° C. at the surface and 11° C. at 1,000 feet. If parcel E (approximately 1 cubic foot of air) is lifted by some force to an altitude of 1,000 feet, it will expand and cool adiabatically to a temperature of 12° C. at 1,000 feet ((B), fig 5-4). The rising parcel of air E is now warmer than its surroundings, and will continue to rise even though the original lifting force is removed. The air is not able to

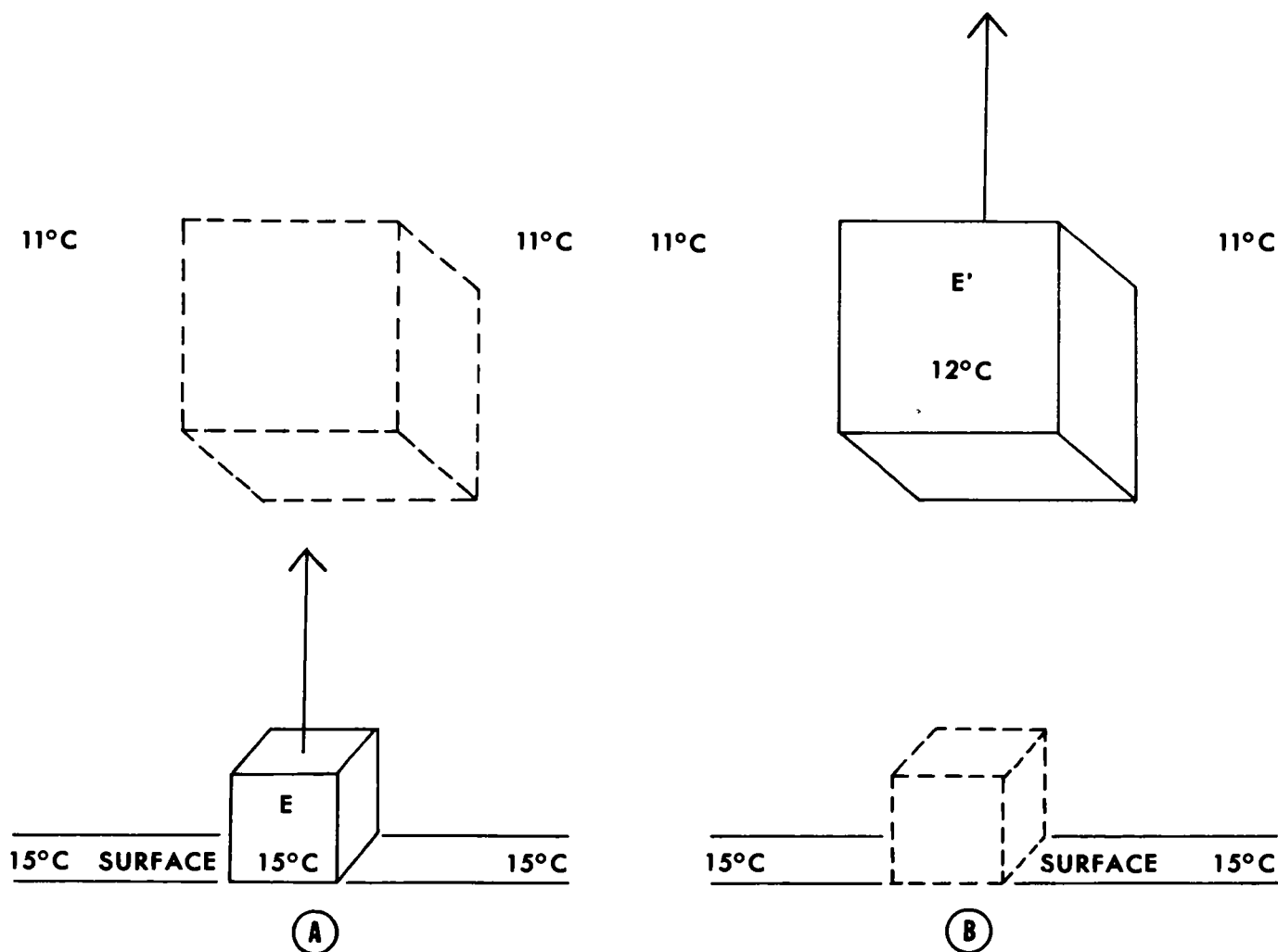
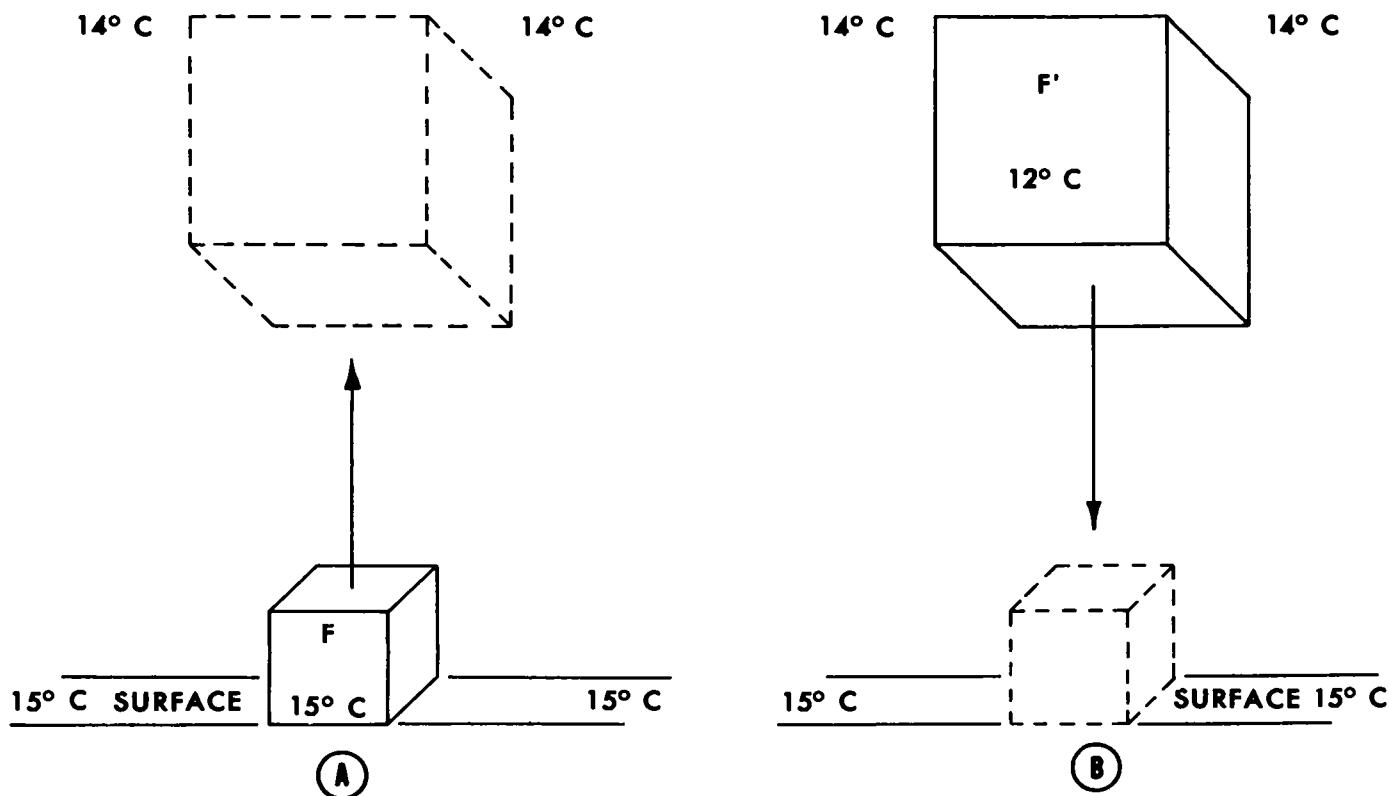


Figure 5-4. Absolute instability in the atmosphere.

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Figure 5-5. Absolute stability in the atmosphere.

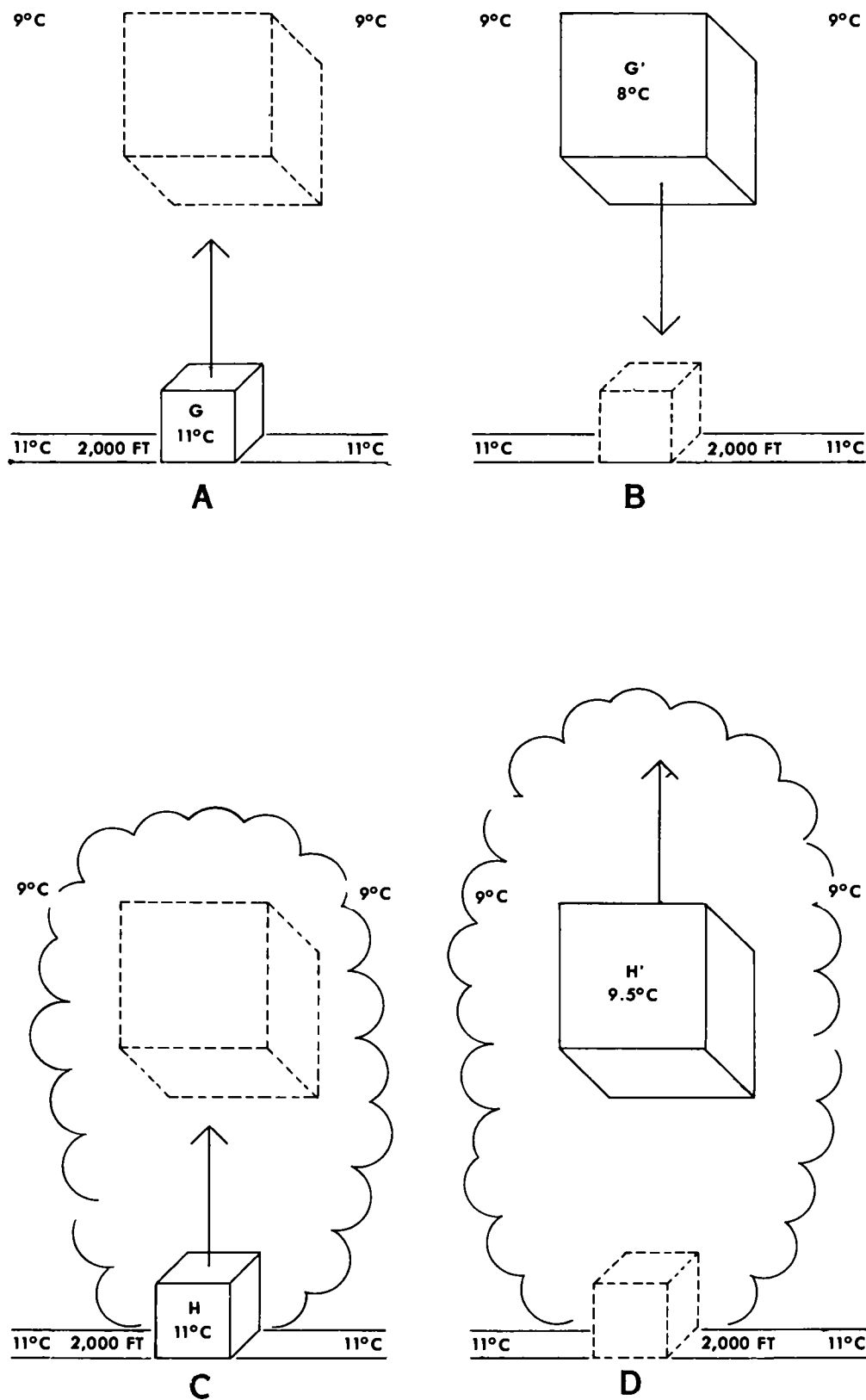
resist vertical motion but, once lifted, will continue to rise by itself—it is unstable. If the observed lapse rate is greater than 3° C. per thousand feet, air is absolutely unstable.

b. Absolute Stability (Fig 5-5). Figure 5-5(A) shows a parcel of unsaturated air at the surface with a temperature of 15° C. The observed lapse rate is 1° C. per thousand feet, being 15° C. at the surface and 14° C. at 1,000 feet. If parcel F is lifted by some force to an altitude of 1,000 feet, it will expand and cool adiabatically to a temperature of 12° C. at 1,000 feet ((B), fig 5-5). The rising parcel of air F is now colder and heavier than its surroundings. As soon as the lifting force is removed, parcel F will sink back to its original level at the surface. The air resists vertical motion—it is stable. When the observed lapse rate is less than 1.5° C. per thousand feet, the air is absolutely stable.

c. Conditional Instability (Fig 5-6). Normally, air has an observed lapse rate between 1.5° C. and 3° C. per thousand feet. This means that the air is neither absolutely stable nor absolutely unstable. If the observed lapse rate is between the moist and dry adiabatic lapse rates, the air is *conditionally unstable*. Figure 5-6(A) shows parcel G of unsaturated air at 2,000 feet with a temperature of 11° C. The observed lapse rate is 2° C. per thousand feet, being 11° C. at 2,000 feet and 9° C. at 3,000 feet. If parcel G is lifted

to an altitude of 3,000 feet, it will expand and cool adiabatically to a temperature of 8° C. ((B), fig 5-6). The rising parcel of air G is colder and heavier than its surroundings, and will return to 2,000 feet once the lifting force is removed. As long as the parcel of rising air remains unsaturated (no clouds forming), it acts like stable air and will tend to resist vertical displacement. However, if the air at 2,000 feet becomes saturated, clouds will form throughout the entire lifting process. The heat released from condensation will change the adiabatic rate of cooling from 3° C. to 1.5° C. per thousand feet ((C) and (D), fig 5-6). With the same surface temperature and observed lapse rate as used in (A) and (B), figure 5-6, but with clouds forming, the air will no longer have stable characteristics. If parcel H is lifted to 3,000 feet altitude ((D), fig 5-6), it will expand and cool to 9.5° C. At the 3,000-foot altitude, parcel H will have a temperature one-half a degree warmer than the surrounding air layer. Since parcel H is warmer and lighter than its surroundings, it will continue to rise, and the cloud will continue to develop. The air will act like unstable air if it becomes saturated (if clouds form). This air is said to be conditionally unstable. Clouds forming in this type of air will be of the cumuliform type. Conditional instability is the most common state of stability in the atmosphere.

d. Lifting Condensation Level and the Level of Free



aavnl08

Figure 5-6. Conditional instability.

Convection. The *lifting condensation level* is the altitude to which a parcel of air must be lifted for saturation to occur. This altitude is controlled by the temperature-dew point spread of the air at the earth's surface. The *level of free convection* is the altitude to which air must be lifted by some outside force before it will continue to rise by itself. Figure 5-7 illustrates the lifting condensation level and level of free convection in a parcel of conditionally unstable air which is displaced 4,000 feet (vertically) by a mountain.

(1) At the surface, parcel X (fig 5-7) has a temperature of 15° C. and a dew point of 12° C. As the air is lifted up the windward side of the mountain, it will expand and cool at the appropriate adiabatic rates (3° C. per thousand feet while unsaturated, 1.5° C. per thousand feet when saturated). At the 1,000-foot level the air will have cooled to its dew point temperature. Any further lifting beyond this altitude will produce clouds. Therefore, 1,000 feet is the lifting condensation level for parcel of air X. At this 1,000-foot level the parcel of air would act like stable air because it is colder than the surrounding air layer (13° C.).

(2) As the parcel is further lifted by the upslope flow over the mountain, its temperature gradually becomes the same as that of the surrounding air layers. A state of equilibrium is reached at 3,000 feet.

Any further lifting above 3,000 feet will cause the temperature of the lifted parcel to become warmer than the surrounding air. Therefore, 3,000 feet is the level of free convection in this parcel of air.

(3) By the time the air reaches the top of the mountain at 4,000 feet, the rising parcel is 0.5° C. warmer than the surrounding air layer, so it will continue to rise without further mechanical lifting. The air becomes unstable after it has been lifted beyond the level of free convection. The mass of air from which the parcel was displaced is conditionally unstable; the observed lapse rate is between the moist and dry adiabatic lapse rates. As clouds form in the displaced air (decreasing the water *vapor* content of the air), the dew point temperature decreases directly with the air temperature of the parcel.

5-6. Stability and Moisture Content

Warm air with a large amount of water vapor produces the most violent weather phenomena (hurricanes, thunderstorms, and tornadoes). As this air travels across the earth, sufficient lifting will release latent heat of condensation and produce unfavorable flying conditions. The temperature of the air, the degree of lifting, the observed lapse rate, and the moisture content determine the type and severity of the weather.

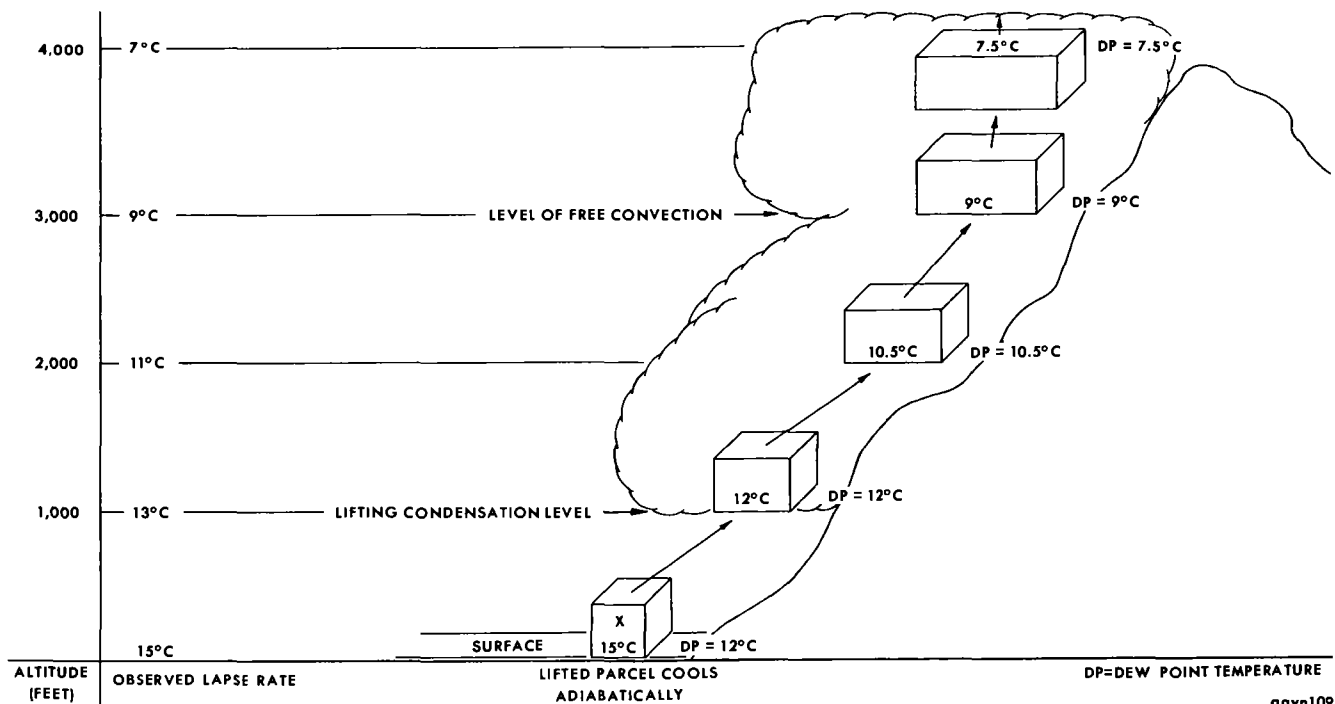


Figure 5-7. Conditionally unstable air being lifted.

Section II. INTERPRETING THE ATMOSPHERIC SOUNDING DIAGRAM

5-7. The Radiosonde Observation

The atmospheric sounding diagram is a vertical-plot graph of pressure, temperature, and moisture data above a selected geographical location. The raw data is gathered by means of a radiosonde instrument carried aloft by balloon—pressure, temperature, and dew point are evaluated from the radiosonde transmissions. Transcribed to the atmospheric sounding diagram (Skew T, log p), the graphic picture represents the physical properties of the atmosphere over a particular geographical location at a particular time. The graphic display includes stability, cloud layers, freezing level, potential icing levels, and the temperature at any altitude.

5-8. Coordinates

a. Pressure. Isobars (line AA, fig 5-8) are represented by straight horizontal brown lines arranged on a logarithmic scale (log p). Pressure values are shown in brown at 50-millibar increments, from the 1,050- to the 100-millibar level. The height, in feet, of each 50-millibar level (US Standard Atmosphere) is in parentheses under the pressure label along the left edge of the chart. The section of the diagram from 400 to 100 millibars can also be used for a range of 100 to 25 millibars by reference to the auxiliary pressure scale printed in brackets outside the left edge and inside the right edge of the chart.

b. Temperature. Isotherms (line BB, fig 5-8) are shown as straight brown lines sloping upward to the right (Skew T). Temperature is represented on a linear scale and the isotherms are equally spaced. They are labeled at 5° C. intervals in brown. Every other 10° C. increment is shaded green.

c. Dry Adiabats. The rate at which dry air cools or warms during adiabatic ascent or descent is depicted by curved brown lines, concave at the top, and sloping upward to the left (line CC, fig 5-8). These lines cross the 1,000-millibar isobar at each 2° C. and are labeled at 10° C. intervals in brown within the chart, on the right and left edge, and on the top. The figures in parentheses are dry adiabatic values for using the chart between the altitudes of 100 to 25 millibars.

d. Moist Adiabats. Representations of the rate at which saturated air cools during ascent are called *moist adiabats*. These curved green lines (line DD, fig 5-8) slope upward to the left. They cross the 1,000-millibar isobar at 2° C. intervals and are labeled along the 530- and 200-millibar isobars in green. Moist adiabats do not extend above the 200-millibar level.

e. Mixing Ratio. The mixing ratio is defined as the mass of water vapor per unit mass of perfectly dry air. Lines of constant saturation mixing ratio are shown as dashed green lines sloping upward to the right (line EE, fig 5-8). They are labeled in grams of water vapor per thousand grams of dry air, at the base of the chart in green. These lines extend only to the 200-millibar level.

f. Thickness Scale. The thickness of several standard layers is shown by horizontal scales in black at the middle of each layer (line FF, fig 5-8). These scales are labeled in hundreds of feet (i.e., 90 means 9,000 feet). Tick marks indicate increments of 10 feet.

g. Temperature-Pressure-Height Nomogram. to find the height of the 1,000-millibar level, a nomogram is printed in black with a pressure-height scale along the left edge and a temperature scale along the upper edge.

h. Standard Atmosphere Scale and Curve. An International Civil Aviation Organization (ICAO) standard atmosphere height scale, printed in black, is located along the right edge of the diagram. The height in kilometers is printed on the left side of the line and in thousands of feet on the right side.

i. Free Air Temperature Curve. The free air temperature curve of the ICAO standard atmosphere is represented by a heavy brown line curving from 17° C. at the 1,050-millibar level to -55° C. at the 233-millibar level. From the 233-millibar level, the curve parallels the -55° C. isotherm to the top of the chart (line CG, fig 5-8, parallels a portion of the ICAO standard atmosphere line).

j. Wind Plotting Staffs. Just to the left of the standard atmosphere height scale, three vertical black lines are printed, with circles at the 1,000-, 850-, 700-, 500-, 400-, 300-, 250-, 200-, 150-, and 100-millibar levels. A dot is printed at the standard wind-reporting levels. These points are used for plotting wind velocities on the chart.

k. Fahrenheit Temperature Scale. Across the base of the chart, a horizontal line, graduated in degrees Fahrenheit, may be used for conversion of centigrade temperatures. The centigrade isotherm may be pro-

jected by placing a straightedge along the isotherm to intersect the Fahrenheit scale.

5-9. Analysis of Atmospheric Sounding for Aviators

a. *Observed Temperature Lapse Rate.* The observed temperature lapse rate, also referred to as the temperature *lapse curve* or *sounding curve*, represents the actual temperature lapse rate in the atmosphere, as determined from the radiosonde. The aviator can obtain the temperature for any desired flight level from the temperature lapse rate and altitude scale by (1) referring to the desired height on the altitude scale, (2) locating a point on the temperature sounding horizontal to the altitude, and (3) reading the temperature ordinates (isotherms). The temperature sounding curve is indicated by an unlettered solid black line (fig 5-8).

b. *Observed Dew Point Temperature Lapse Rate.* The dew point temperature lapse rate, indicated by an unlettered black broken line (fig 5-8) is determined from the radiosonde observation and is used in determining the moisture content for any desired level in

the atmosphere. It is also used for determining cloud bases, cloud tops, cloud types, icing conditions, the type of potential icing, and the stability of the atmosphere.

c. *Absolutely Stable Air.* The observed lapse rate (line AB, fig 5-9) shows a temperature of 14°C . at the 963-millibar level and -2°C . at the 525-millibar level. The difference in temperature between the two levels is 16°C . If unsaturated air having a temperature of 14°C . is lifted from the 965-millibar level, it will not cool according to this line, but according to the dry adiabatic rate. It will follow the dry adiabat until it becomes saturated (line AA₁, fig 5-9). The saturated air at point A, then follows the moist adiabat to the 525-millibar level (A₂). By the time the air reaches the 525-millibar level, it will have cooled from 14°C . to a temperature of -22°C ., and will be much cooler than the layer of air through which it is rising. Since it is cooler than the surrounding air, it will be heavier and will return to its former position when the lifting force is removed. This air is absolutely stable.

d. *Absolutely Unstable Air.* Line CD (fig 5-9) indicates a temperature of 12°C . at the 960-millibar level and a -11°C . temperature at the 790-millibar level.

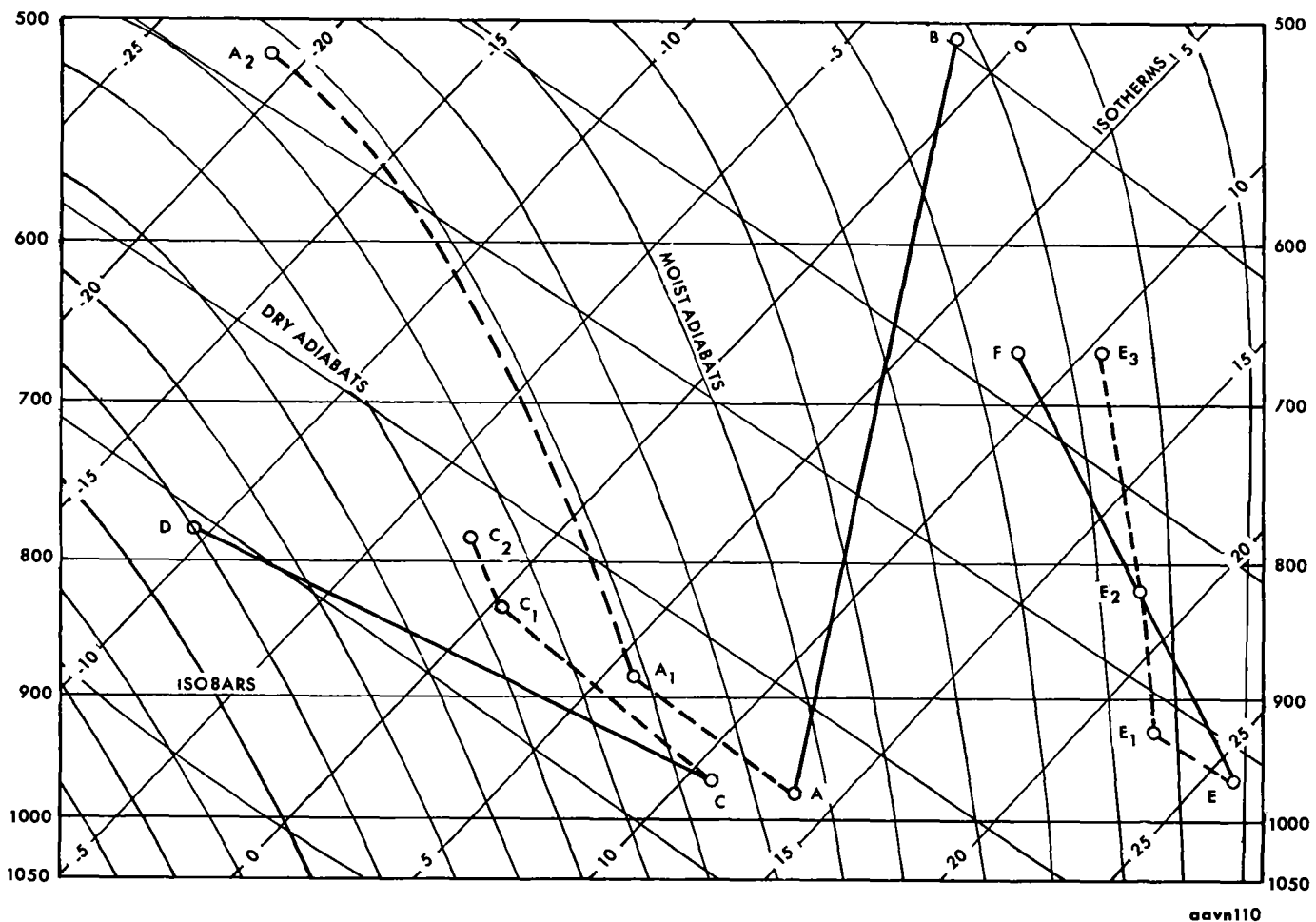


Figure 5-9. Analysis of atmospheric stability.

The temperature difference between the two altitudes is 23° C. If a parcel of air is lifted between these two isobars, it will follow the dry adiabat until it reaches saturation (line CC₁). From that point it will follow the moist adiabat. During this ascent (from C₁ to C₂), the parcel will cool only 15° C. and will be warmer than the surrounding air; it will continue to rise. The air is absolutely unstable.

e. Conditional Instability. The difference in temperature (represented by line EF fig 5-9), between points E and F, is 20° C. If a parcel of air is lifted from point E, it will follow the dry adiabat until it becomes saturated (point E₁). The air will then follow the moist adiabat. The lifted parcel will remain cooler than its surroundings, acting like stable air until it reaches point E₂. The moisture content and amount of lifting is the condition that determines the stability of the layer. After passing E₂, the rising parcel will be warmer than the surrounding air and will become unstable. This air is conditionally unstable. It had to be lifted above the lifting condensation level to the level of free convection before it would continue to rise by itself.

f. Quick Analysis of Stability on the Atmospheric Sounding Diagram. When the slope of the sounding curve (observed lapse rate) is to the right of the moist adiabat ((A), fig 5-10), the air is absolutely stable. When the slope of the sounding curve is to the left of the dry adiabat ((B), fig 5-10), the air is absolutely unstable. When the slope of the sounding curve is between the moist and the dry adiabats ((C), fig 5-10), the air is conditionally unstable. This same method can be used for determining stability on the USAF Skew T, log p diagram (fig 5-8): the layer from the surface to the 900-millibar level is conditionally unstable, the layer from the 900-millibar level to the 800-millibar level is stable, and the layer from the 800-millibar level to the 715-millibar level is stable.

g. Cloud Levels.

(1) A radiosonde sounding for temperature and dew point is plotted on the atmospheric sounding diagram (fig 5-8). Some selected approximate temperatures and dew point temperatures, from the sounding, are indicated below.

Millibar levels	°C. Free air temperature (solid black line)	°C. Dew point temperature (dashed black line)
975	5.0	1.0
900	-1.0	-2.5
800	-6.0	-6.5
780	-3.5	-3.5
715	+1.5	-4.0
600	-7.5	-12.5
520	-17.5	-20.5
450	-27.5	-28.5
400	-33.5	-34.5

(2) Clouds should be assumed to be present when the temperature-dew point spread is 2° C. or less (fig 5-8), the base of the lower cloud layer is at

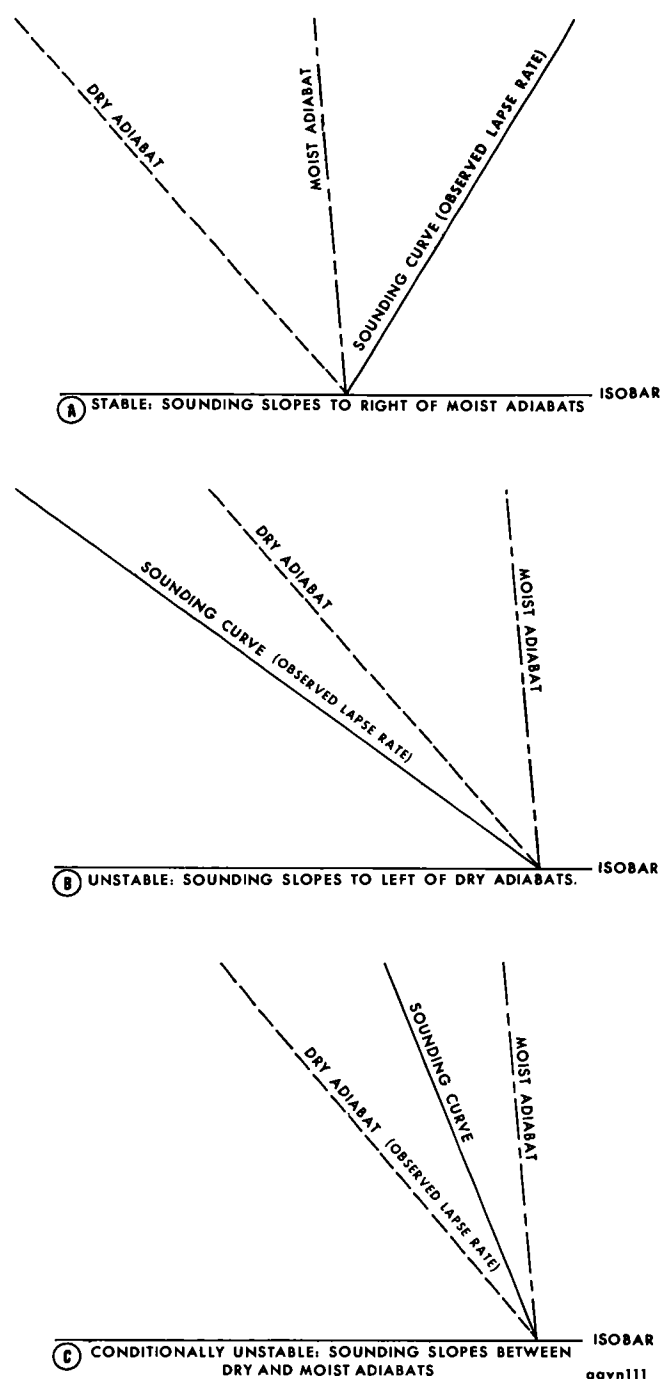


Figure 5-10. Stability criteria.

the 910-millibar level, because at this point the temperature and the dew point are within 2° C. of each other. The top of the cloud layer is at the first point at which the temperature and dew point curve are more than 2° C. apart.

(3) Further analysis of the chart shows that between the 755-millibar and the 470-millibar level, the spread between free air temperature and dew point temperature is more than 2° C.—there are no clouds between these levels.

(4) At the 470-millibar level, the temperature

and dew point again come within 2° C. of each other and clouds will exist at that altitude. These clouds extend up to the 400-millibar level.

h. Cloud Types. The general type of clouds can be determined by knowing the stability of the air at the level where clouds exist. Stratiform clouds are associated with stable air, and cumuliform clouds with unstable air. After determining the stability and referring the height of the base of the cloud to the altitude scale, the cloud can be placed in its general classification (high, middle, or low) and the type can then be determined (cumuliform or stratiform). The clouds represented in figure 5-8 are stratus (low layer) and cirrostratus (high layer).

i. Icing. (Also see *Icing*, chap 9.)

(1) *General.* Clear ice will form on the structure of an aircraft when clouds are present, the air temperature lies between 0° C. and -10° C., and the air is unstable. Rime ice will form in unstable cloud layers at temperatures between -10° C. and -20° C. because most of the larger water droplets will have been replaced by ice crystals. If an air layer is stable, rime ice will form in visible moisture at temperatures between 0° C. and -20° C.

(2) *Freezing and icing levels.*

The free air temperature line (fig 5-8)

crosses the 0° C. temperature ordinate at approximately the 910-millibar level (the freezing level) and does not recross the 0° C. temperature ordinate until it reaches the 735-millibar level. Since visible moisture and freezing temperatures exist in this area, and the air is stable, rime ice will form on the structure of an aircraft passing through it.

From the 735-millibar to the 690-millibar level temperatures are above freezing, but above the 690-millibar level temperatures are below freezing. Because no visible moisture is present within the layer, between 690 millibars and 470 millibars, no structural icing will form.

Above the 470-millibar level, visible moisture is present, but due to extremely low temperatures it is in the form of ice crystals and serious icing will not occur.

j. Temperature Inversion. The temperature sounding curve (fig 5-8) indicates that the air becomes increasingly colder with altitude until the 800-millibar level is reached. The temperature increases with altitude between the 800-millibar and 715-millibar levels; therefore, a temperature inversion exists in this layer. Clouds, haze, dust, and smoke layers often restrict visibility beneath such inversion layers.

6-1. General

An *air mass* is a large body of air whose physical properties (mainly temperature and humidity) are relatively uniform horizontally. The various types of air masses are identified by the geographical area where they form. A periodic interchange between warm air masses and cold air masses characterizes the weather of the Temperate Zones. Warm air masses predominate in the summer and cold air masses in the winter, although either may exist almost anywhere in the Temperate Zone at any season.

6-2. Factors Which Determine the Characteristics of An Air Mass

The *characteristics* of an air mass include the stability, cloud types, sky coverage, visibility, precipitation, icing, and turbulence in addition to the basic properties of humidity and temperature. The terrain surface underlying the air mass is the primary factor in determining air mass characteristics.

a. The characteristics of an air mass are acquired in the source region. The *source region* is the surface area over which an air mass originates. The ideal source region has a uniform surface (all land or all water), a uniform temperature, and is an area in which air stagnates to form high pressure systems.

b. Two secondary factors affecting air mass characteristics are—

(1) *The air mass trajectory*. The path over which an air mass travels after expanding and leaving the source region is called the *air mass trajectory*. Over a period of time, the trajectories of each specific air mass form a general pattern. Air masses often move over several different types of surfaces (mountains, plains, plateaus, barren land, water, snow-covered areas, etc.) along their trajectories, and each surface affects the moving air mass.

(2) *The age of the air mass*. The length of time the air mass has been away from the source region is called the *age of the air mass*. As an air mass moves along its trajectory, its characteristics are changed by the underlying surface; the air mass is *modifying*. The extent of modification depends upon (a) the temperature and moisture contrast between the air and the surface, (b) the terrain features, and (c) the

time the air mass has been away from the source region. An “old” air mass may be modified to such an extent that its original characteristics disappear and the weather within the air mass completely changes.

6-3. Air Mass Classification

The standard classification of air masses describes both the geographic and thermodynamic aspects of the air mass.

a. The geographic classification identifies the source region (temperature and moisture).

(1) *Temperature*. The latitude of the source region determines the relative air mass temperature. Therefore, capital-letter abbreviations which identify the latitude of the source region are used to indicate the air mass temperature; i.e., A—Arctic, P—Polar, T—Tropical, and E—Equatorial. The two indicators most commonly used in Temperate Zone weather analysis are P—Polar and T—Tropical.

(2) *Moisture*. The relative moisture content is indicated by a small-letter abbreviation for the type of surface (land or water) over which the air mass originates. A land-source air mass is designated by the small letter “c” to indicate a continental air mass; a water-source air mass is designated by the small letter “m” to indicate a maritime air mass. These small-letter moisture designators precede the capital-letter temperature designators. For example, mP indicates a maritime polar or moist cold air mass; cP indicates a continental polar or dry cold air mass.

Note. Maritime air has a much higher moisture content than continental air; thus, precipitation and cloudiness will be more abundant in maritime than in continental air masses.

b. The thermodynamic classification indicates stability or instability. When the air is warmer than the surface over which it is moving, it is cooled by contact with the cold ground and becomes more stable; when the air mass is colder than the surface over which it is moving, it is heated from below and convective currents and instability result. A small

letter "w" indicates that the air is warmer than the surface over which it is flowing and is, therefore, stable. A small letter "k" indicates that the air is colder than the surface over which it is flowing and is, therefore, unstable.

6-4. Air Mass Designation

The following designators identify air masses that frequently affect the northern Temperate Zone:

- mPk (maritime polar cold) has its source region over an ocean north of 40° north latitude and is colder than the surface over which it is traveling.
- mPw (maritime polar warm) has its source region over oceans north of 40° north latitude and is warmer than the surface over which it is traveling.
- mTw (maritime tropical warm) has its source region over oceans between 10° and 30° north latitude and is warmer than the surface over which it is traveling.
- mTk (maritime tropical cold) has its source region over oceans between 10° and 30° north latitude and is colder than the surface over which it is traveling.
- cPk (continental polar cold) has its source region over land areas generally between 40° and 60° north latitude and is colder than the surface over which it is traveling.
- cT (continental tropical) has its source region over a land area south of about 30° north latitude.

6-5. General Characteristics of Air Masses

The following weather conditions are typical of the air masses with which they are identified. Knowledge of these weather characteristics will aid an aviator in predicting, with considerable accuracy, the flying conditions likely to be found within any given air mass.

a. Cold (k Type) Maritime Air Mass. General characteristics of a cold maritime air mass are—

- (1) Cumulus- and cumulonimbus-type clouds.
- (2) Generally good ceilings (except within precipitation areas).
- (3) Excellent visibility (except within precipitation areas).
- (4) Pronounced air instability (turbulence) in lower levels due to convective currents.
- (5) Occasional local thunderstorms, heavy showers, hail, or snow flurries.

b. Warm (w Type) Maritime Air Mass. General characteristics of a warm maritime air mass are—

- (1) Stratus- and stratocumulus-type clouds and/or fog.
- (2) Low ceilings (often below 1,000 feet).
- (3) Poor visibility (since haze, smoke, and dust are held in lower levels).
- (4) Smooth, stable air with little or no turbulence.

- (5) Occasional light continuous drizzle or rain.

c. Continental air mass. Continental air masses are associated with good flying weather; i.e., clear skies or scattered high-based cumuliform clouds, unlimited ceilings and visibilities, and little or no precipitation. However, two exceptions are—

- (1) Intense surface heating by day may produce strong convection (turbulence) with associated gusts and blowing dust or sand (para 6-11).
- (2) Movement of cold dry air over warm moist water surfaces may produce dense steam fog and/or low overcast skies with drizzle or snow. If the air continues its movement into mountainous terrain, heavy turbulence, icing, and showers may develop (para 6-9a).

6-6. Source Regions and Trajectories

a. Source Regions. To understand the behavior of the weather within the various air masses, it is necessary to know the general characteristics of their source regions. The source regions of air masses in the Northern Hemisphere and their general characteristics are as follows:

(1) *Arctic air mass source region.* In the general circulation pattern, there is a permanent high pressure system surrounding the geographical pole. Within the high pressure area the air moves slowly around the arctic ice cap, forming an arctic air mass. Characteristically, arctic air in the source region is dry aloft and very cold and stable in the lower levels.

(2) *Continental polar source region.* Polar air is not as cold as arctic air. The continental polar source regions consist of all the land areas dominated by the Canadian and Siberian high pressure cells. In the winter, these regions (generally between latitudes 45° north and 65° north) are completely covered with a layer of snow and ice. Even in the summer, much of the ice remains and the areas are still relatively cold. Because of the intense cold and the absence of water bodies, very little moisture evaporates into the air.

Note. The word polar, when applied to air mass designation, does not mean air around the poles. Air masses in the immediate polar region are designated as arctic.

(3) *Maritime polar source region.* The maritime polar source region consists of the open unfrozen polar sea region in the Atlantic and Pacific oceans. There water surfaces are a source of considerable moisture for polar air masses. Air masses forming over this polar sea region are moist in the lower layers, but the vapor content is limited by the cool air temperature.

(4) *Continental tropical source region.* A continental tropical source region can be any significant

land area in the tropical regions, generally between latitudes 10° and 30° north and south. The large land masses in the tropical region are usually desert areas, such as the Sahara or Kalahari of Africa, the Arabian Desert, and the entire region of inland Australia. The air lying over these regions is hot, dry, and unstable.

(5) *Maritime tropical source region.* The maritime tropical source region is that vast zone of open tropical sea along the belt of subtropical anticyclones north of the Equator (Pacific and Bermuda highs). Semipermanent high pressure cells stagnate over the northern edge of the tropical source regions throughout most of the year. The air temperature is warm in these low latitudes, and the water vapor content of the air is very high.

(6) *Equatorial source region.* The equatorial source region is located in the vicinity of the thermal Equator (doldrums) from about 10° north latitude to 10° south latitude. It is essentially an oceanic belt, very warm, and very high in moisture content. Convergence of the trade winds from both hemispheres and intense insolation over this region cause voluminous lifting of the moist, unstable air to high levels.

The weather is characterized by considerable thunderstorm activity throughout the year.

b. Trajectories. As an air mass leaves its source region, it is modified by the different types of surfaces over which it moves, and by the nature and methods of heat transfer taking place within the air mass. For example:

(1) Cold dry air moving over a surface that is warm and moist will soon become warm and moist in the surface layer. The air mass is classified as cP, even though the surface layer has been modified by the trajectory over warm water. The upper air still retains its cold dry characteristics. However, when an air mass moves into a different source region, such as a cP air mass from Canada moving into an mP source region in the North Atlantic, the modification over several days may affect the mass to the extent that it can be reclassified from cP to mP.

(2) Warm moist air moving over hot dry continental areas will lose some of its moisture each day as surface heating causes clouds to form and precipitation to occur. The longer the air mass is out of its source region, the less it will have of its source region characteristics. An "old" air mass tends to take on the characteristics of the surface over which it is moving.

Section II. AIR MASSES AFFECTING THE UNITED STATES

6-7. General

The basic considerations in air mass analysis (para 6-1 through 6-6) are applicable to a study of air mass weather throughout the world. However, local variables, such as the distribution and orientation of mountain ranges, the flow and temperature of ocean currents, prevailing pressure patterns, and the distribution of land and water surfaces are too numerous to allow a detailed worldwide air mass analysis in the scope and space of this manual. These world air mass characteristics are discussed briefly and generally in appendix C. This section presents a more detailed analysis of the air masses affecting the weather of the continental United States (fig 6-1 and 6-2).

6-8. Maritime Polar Air Masses

Maritime polar air masses which invade the United States arrive from two different source regions. One of these source regions is located in the North Pacific Ocean; the other in the northwestern portion of the North Atlantic Ocean. Those air masses originating over the Pacific Ocean dominate the weather conditions of the Pacific coast of the United States and western Canada. Those air masses originating over the North Atlantic Ocean frequently appear during

the winter over the northeastern coast of the United States.

a. Winter.

(1) *Pacific coast.* Many of the maritime polar air masses which invade the Pacific coast originate in the interior of Siberia (para 6-6b(1)). They have a long overwater trajectory and, during their trajectory over the Pacific Ocean, are unstable in the lower layers (fig 6-3). As they invade the west coast, they are cooled from below by a cool ocean current and coastal area and become more stable. Along the Pacific coastal regions, stratus and stratocumulus clouds are common in these air masses. Maritime polar air masses cause heavy cumuliform cloud formation and extensive shower activity as they move eastward up the slopes of the mountains. East of the mountains, the air descends and is warmed adiabatically. This adiabatic warming results in decreased relative humidity, and the skies are generally clear (fig 6-4).

(2) *Northeast section of United States.* In the northeastern section of the United States, maritime polar air moves into the New England States from the northeast. These air masses are usually colder and more stable than those entering the west coast from a northwest direction. Low stratiform clouds with light continuous precipitation and generally

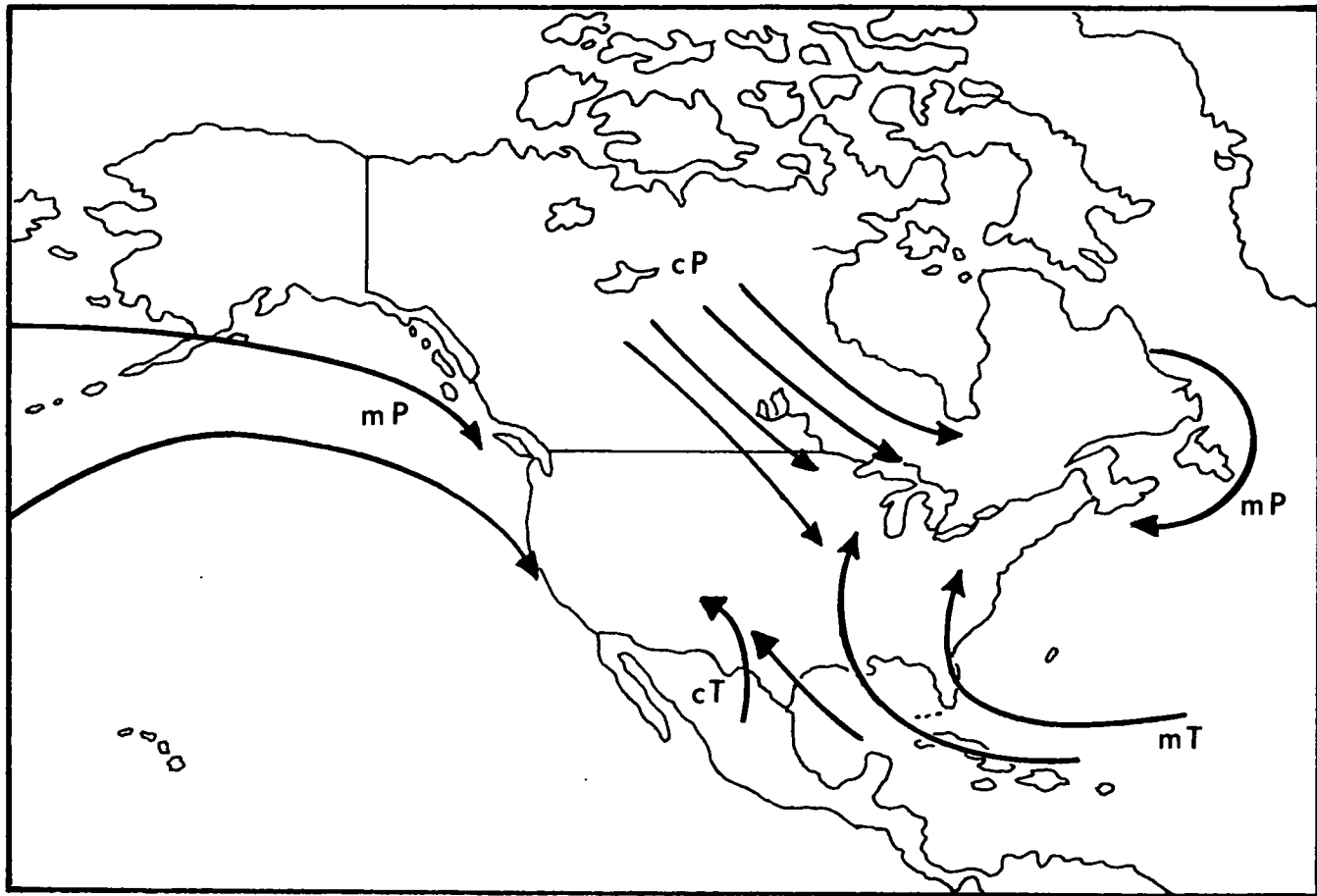


Figure 6-1. Air mass source regions and trajectories (July).

strong winds occur as these air masses move inland.

b. Summer. Since water temperatures are cooler than adjacent land temperatures in the summer, maritime polar air masses entering the Pacific coast become unstable because of the surface heating. In the afternoon, cumuliiform cloud formations and widely scattered showers occur. At night, fog and low stratiform clouds are common on the coastal regions, especially along the coast of California. When the air masses cross the mountains, they lose a considerable amount of moisture on the western mountain slopes. The orographic lifting intensifies the development of cumuliiform clouds on the windward slopes. These cloud buildups are accompanied by heavy showers with low ceilings and visibilities.

6-9. Continental Polar Air Masses

a. Winter. Continental polar air masses that invade the United States during winter originate over Canada and Alaska. They are stable in the source regions. As the air masses move southward into the United States, they are heated by the underlying surface. During daylight hours, the air is generally unstable near the surface and the sky is usually clear. At night the air tends to become more stable. When these cold

dry air masses move over the warmer waters of the Great Lakes, they acquire heat and moisture and become unstable in the lower levels (fig 6-5); cumuliiform clouds form and produce snow flurries over the Great Lakes and on the leeward side of the lakes. As the air masses move southeastward, the cumuliiform clouds intensify along the Appalachian Mountains. Continental polar air masses between the Great Lakes and the peaks of the Appalachians contain some of the most unfavorable flying conditions (icing, turbulence, and below-minimum ceilings and visibilities) in the United States during the winter months. Clear skies or scattered clouds are normal east of the mountains.

b. Summer. Cold dry air masses have different characteristics and properties in the summer than in the winter. Since the thawed-out source regions are warmer and contain more moisture, the air is less stable in the surface layers. The air is, therefore, cool and contains slightly more moisture when it reaches the United States. Scattered cumuliiform clouds form during the day in this unstable air, but dissipate at night when the air becomes more stable. When these air masses move over the colder water of the Great Lakes in the summer, they are cooled from below and become stable, resulting in good flying conditions.

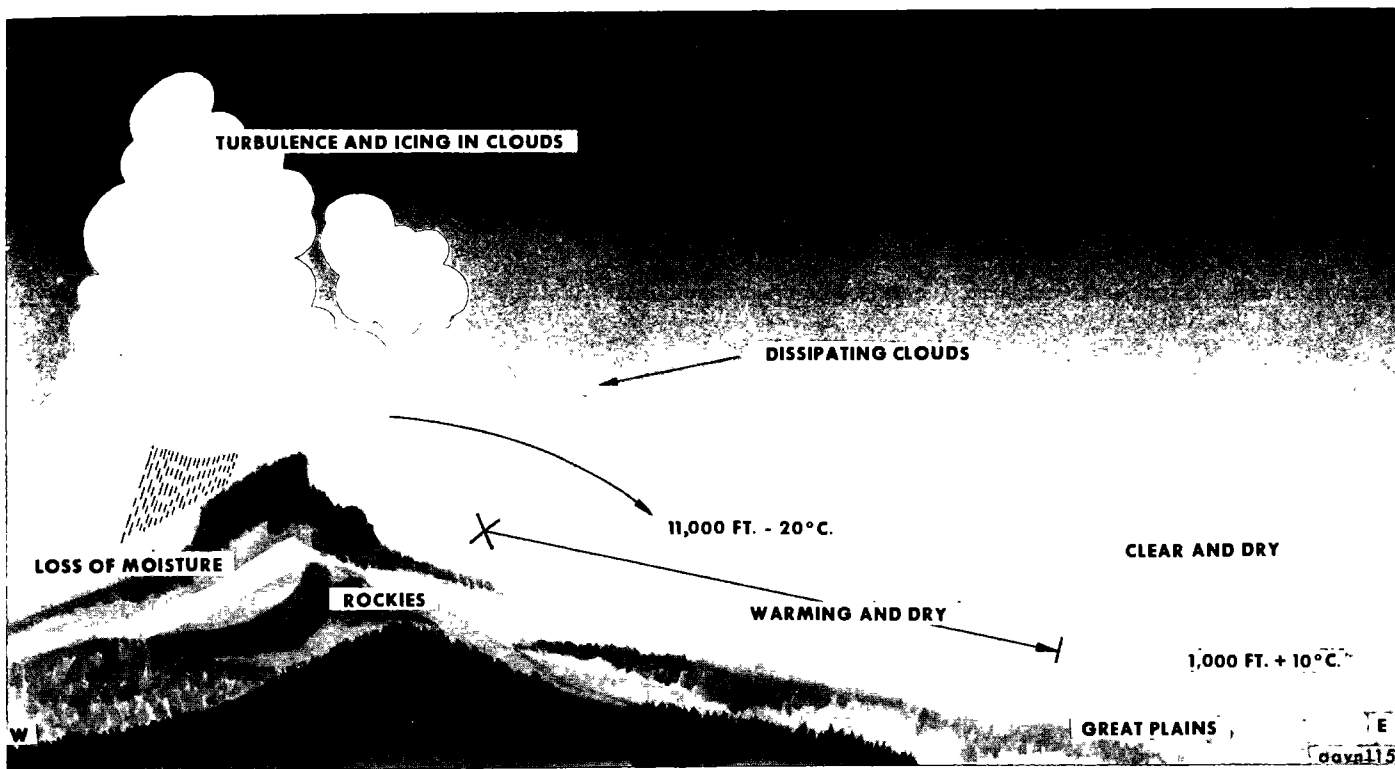


Figure 6-4. Maritime polar air after crossing the Rockies.

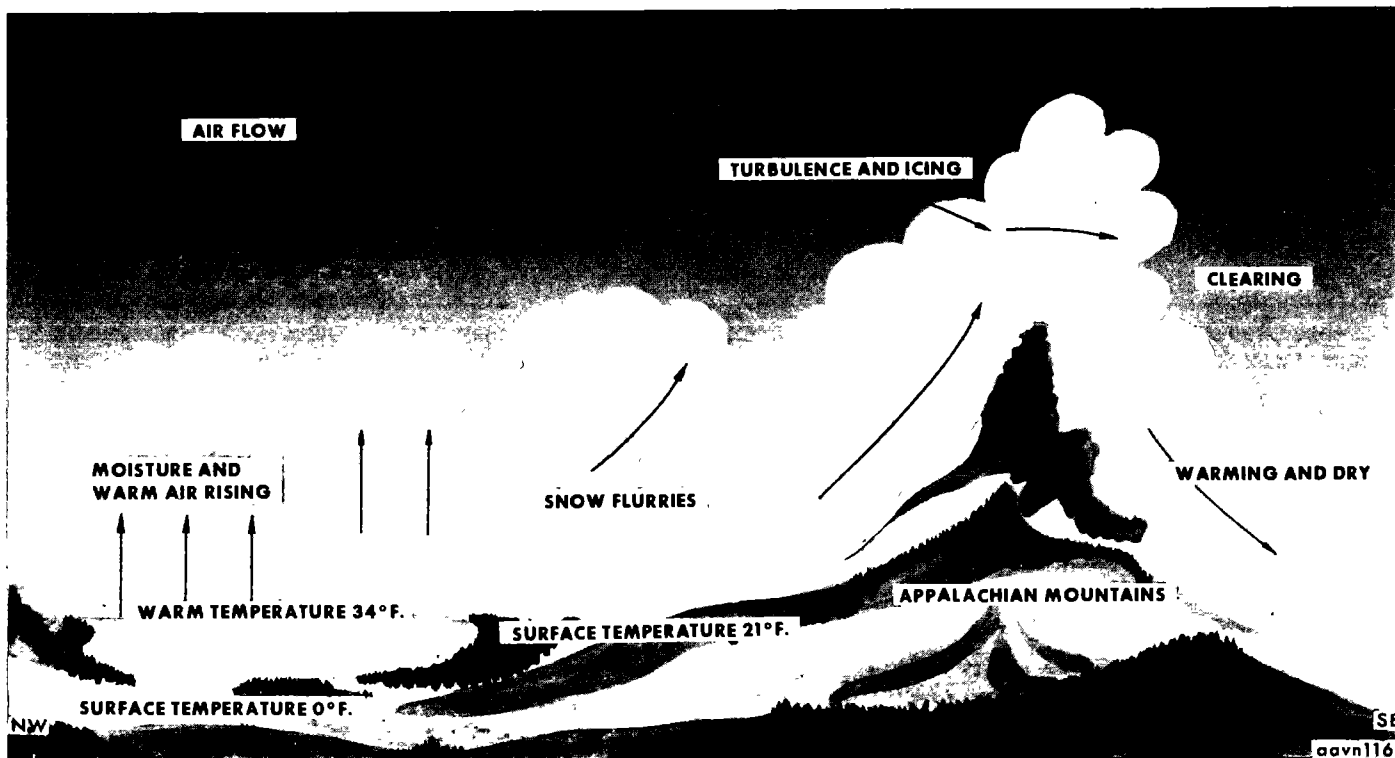


Figure 6-5. Continental polar air moving over the Great Lakes and Appalachians in winter.

6-10. Maritime Tropical Air Masses

Maritime tropical air masses originate over the Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. They move into the United States from the Gulf of Mexico or Atlantic Ocean and are common along the Southeastern and Gulf Coast States. Warm, moist stable air which originates over the Pacific Ocean is rarely observed in Southwestern United States; the prevailing winds in the southwest blow offshore.

a. Winter. Because in winter the land is colder than the water, warm moist air masses are cooled from below and become stable as they move inland over the South Atlantic and Gulf States. Fog and stratiform clouds form at night over the coastal regions (fig 6-6). The fog and clouds tend to dissipate or become stratocumulus during the afternoon. The extent to which the cloudiness and fog spread inland is dependent on the difference between the surface temperature and the air temperature. When surface temperatures are cold, fog and stratiform clouds extend inland for considerable distances (throughout Eastern United States). When land temperatures are extremely cold, extensive surface temperature inversions develop. Under such conditions, daytime heating usually does not eliminate the inversions, and the fog and stratiform clouds may persist for several days. In winter when the air moves over the Appalachian Mountains, the adiabatic cooling produced by orographic lifting (fig 6-6) causes heavy cumuliform clouds to form on the windward side. Extremely low ceilings, poor visibility, moderate turbulence, and

moderate icing typify winter flying conditions in the area.

b. Summer. Warm moist air covers the eastern half of the United States during most of the summer. Since the land is normally warmer than the water, particularly during the day, this air mass is heated from below by the surface and becomes unstable as it moves inland. Along the coastal regions, stratiform clouds are common during the early morning hours. These stratiform clouds usually change during the late morning to scattered cumuliform clouds. By late afternoon, extensive areas of widely scattered thunderstorms normally develop. In maritime tropical air masses, cumuliform clouds and thunderstorms are usually more numerous and intense on the windward side of mountain ranges, in squall lines, and in prefrontal activity.

6-11. Continental Tropical Air Masses

Continental tropical air masses are observed primarily in the Mexico-Texas-Arizona-New Mexico area (their source region), and only in the summer. These air masses are characterized by high temperatures, low humidities, and, although extremely rare, scattered cumuliform clouds. The bases of these cumuliform clouds are exceptionally high for this cloud type. Flying is often rough, especially during the daylight hours, because of the great vertical extent of the turbulence. Occasional dust storms present another significant flying hazard; the dust or sand may extend above 10,000 feet and reduce visibility for many hours.

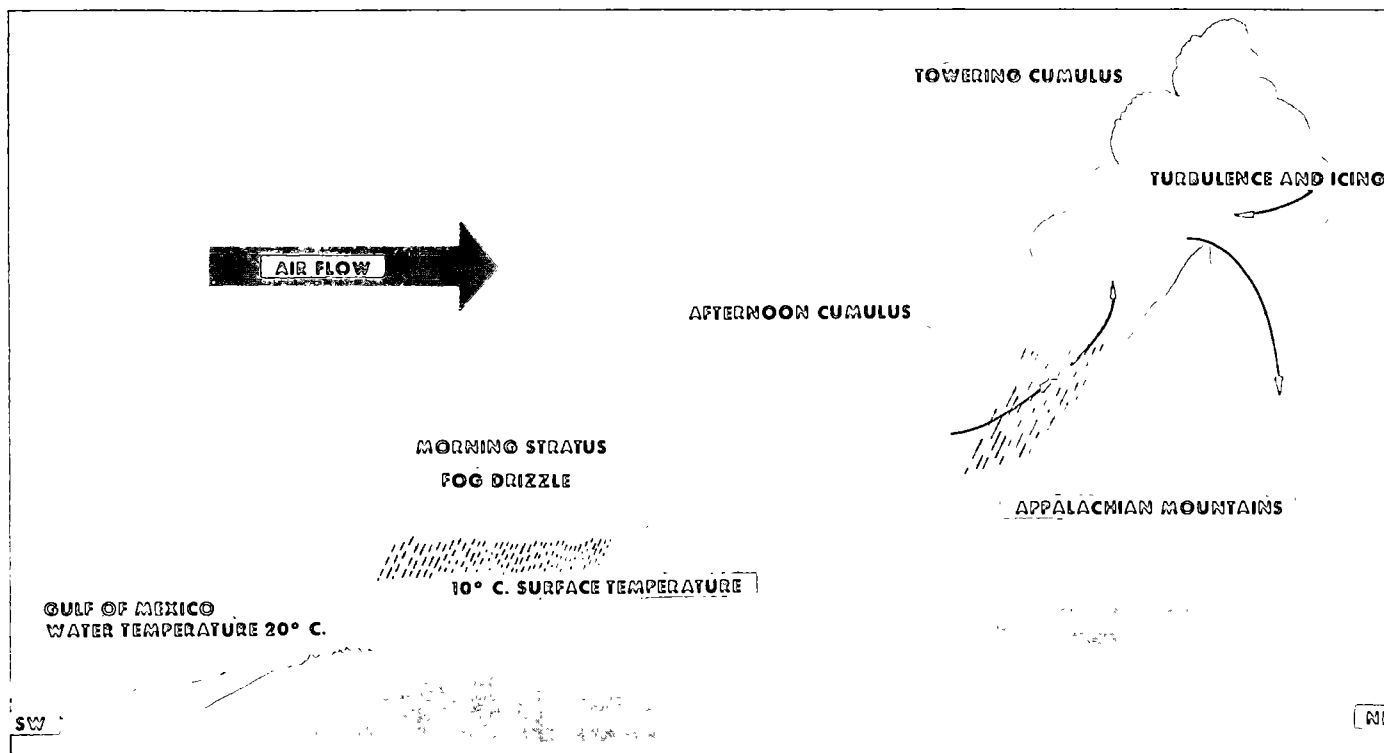


Figure 6-6. Maritime tropical air moving over the Appalachian Mountains in winter.

7-1. General

a. *General.* Fronts are transition zones (boundaries) between air masses that have different densities. The density of air is primarily controlled by the temperature of the air; therefore, fronts in Temperate Zones usually form between tropical and polar air masses. Fronts may also form outside of the Temperate Zone between tropical and equatorial air masses and between arctic and polar air masses. A typical surface weather map shows air mass boundary zones at ground level. Designs on the boundary lines indicate the type of front and its direction of movement. Figure 7-1 depicts polar air (P) over Northern United States and tropical air (T) over Southern United States. Between these air masses, the symbolized black lines indicate the presence of fronts. In local weather stations, fronts may also be indicated by colored lines.

b. *Types.* The four major fronts are the *cold front*, *warm front*, *stationary front*, and *occluded front*. The

name of a front is determined from the movement of the air masses involved.

(1) A *cold front* (line with triangles, fig 7-1) is the leading edge of an advancing mass of cold air.

(2) A *warm front* (line with semicircles, fig 7-1) is the trailing edge of a retreating mass of cold air.

(3) When an air mass boundary is neither advancing nor retreating along the surface, the front is called a *stationary front* (line with alternate triangles and semicircles on opposite sides, fig 7-1).

(4) An *occluded front* (line with alternate triangles and semicircles on the same side, fig 7-1) occurs when a cold front overtakes a warm front at the surface and a temperature contrast exists between the advancing and retreating cold air masses.

c. *Air Mass Boundaries.* Special terms are used to differentiate between the horizontal extent of a front along the surface and the vertical extent of the front into the atmosphere.

(1) The air mass boundaries indicated on the

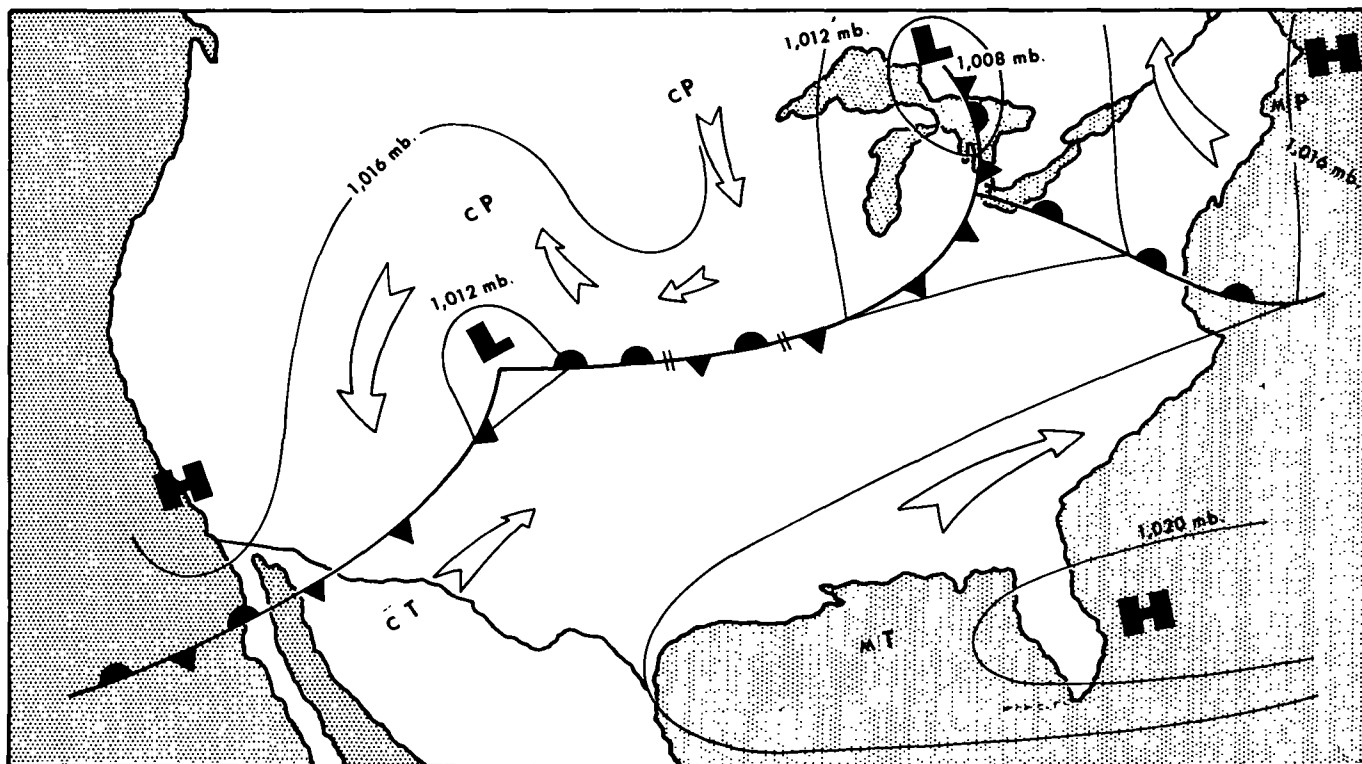


Figure 7-1. Frontal activity over the United States.

surface weather map (fig 7-1) are called *surface fronts*. A surface front is the position of a front at the earth's surface. The weather map shows only the location of fronts on the surface. However, these fronts also have vertical extent; the colder, heavier air mass tends to flow under the warmer air mass. The underrunning mass produces the lifting action of warm air over cold air, causing clouds and associated frontal weather.

(2) The vertical boundary between the warm and cold air masses is a *frontal surface* and slopes upward over the colder air mass. The frontal surface lifts the warmer air mass and produces frontal cloud systems. The slope of the frontal surface varies with the speed of the moving cold air mass and the roughness of the underlying terrain. The typical slope ratio is between 1 to 50 and 1 to 300; i.e., 100 miles behind the surface cold front, the frontal surface may be located anywhere between 2 miles (1 to 50 ratio) and 1,760 feet (1 to 300 ratio) above the earth. The average slope is 1 to 80. Under normal conditions, the angle of inclination (slope ratio) between the frontal surface and the earth's surface is greater with cold fronts than with warm fronts (fig 7-2). The approximate height of the frontal surface over any station is determined from the analysis of upper air observations; e.g., winds aloft, radiosonde, and pilot reports.

d. *Pressure Variation*. As fronts move over a location on the surface, a typical change in pressure occurs. The fronts lie in a trough of low pressure in such a way that, at a given place on the surface, the pressure decreases as a front approaches and increases after it passes.

(1) Because fronts are located along the line of lowest barometric pressure (trough), the wind on the cold air side of a front may vary in direction as much as 180° from the wind on the warm air side.

(2) When an aircraft flies toward a region of lower pressure, it encounters a crosswind from the left. Therefore, when an aircraft approaches a front, it will be drifting to the right or crabbing to the left to remain on course. Once the aircraft passes through the frontal surface, it has passed beyond the region of lowest pressure. (The trough extends from its surface position upward along the frontal surface.) Since the wind will then be from the right of the aircraft, a drift correction to the right will be required to remain on course.

(3) This drift correction principle applies when crossing through any well-defined frontal surface at any altitude. The amount of drift correction required will vary with the intensity of low pressure trough, but is normally least with warm fronts and with occlusions in the later stages of development.

e. *Factors Affecting Frontal Weather*. Weather associated with fronts and frontal lifting is called *frontal weather*. The type and intensity of frontal

weather is determined largely by the speed and slope of the frontal surface, the moisture content of the displaced air mass, and the stability of the displaced air mass. Since these three factors vary, frontal weather may range from a minor wind shift with no clouds or other visible weather activity to severe thunderstorms accompanied by low clouds, poor visibility, hail, severe turbulence, and icing conditions. In addition, weather associated with one section of a front is frequently different from weather in other sections of the same front.

(1) *Speed and slope*. As the front moves over the ground, the amount of friction and the speed of the front regulate the slope of the frontal surface, which in turn affects the amount of turbulence in the frontal cloud system. For example—

(a) When a cold front moves rapidly, its leading edge steepens. This lifts the warm air ahead of the front abruptly, and adiabatic cooling condenses the moisture from the warm air. As the water vapor condenses in the form of clouds, large amounts of energy are released in a relatively narrow band along the leading edge of the front. This concentration of energy causes the turbulence and violent weather associated with the rapidly moving cold front.

(b) When a cold front moves slowly, terrain has less effect on the slope of the frontal surface and the slope is more gradual; the energy released by condensation is spread over a wide area. Turbulence is lessened and the weather is less violent.

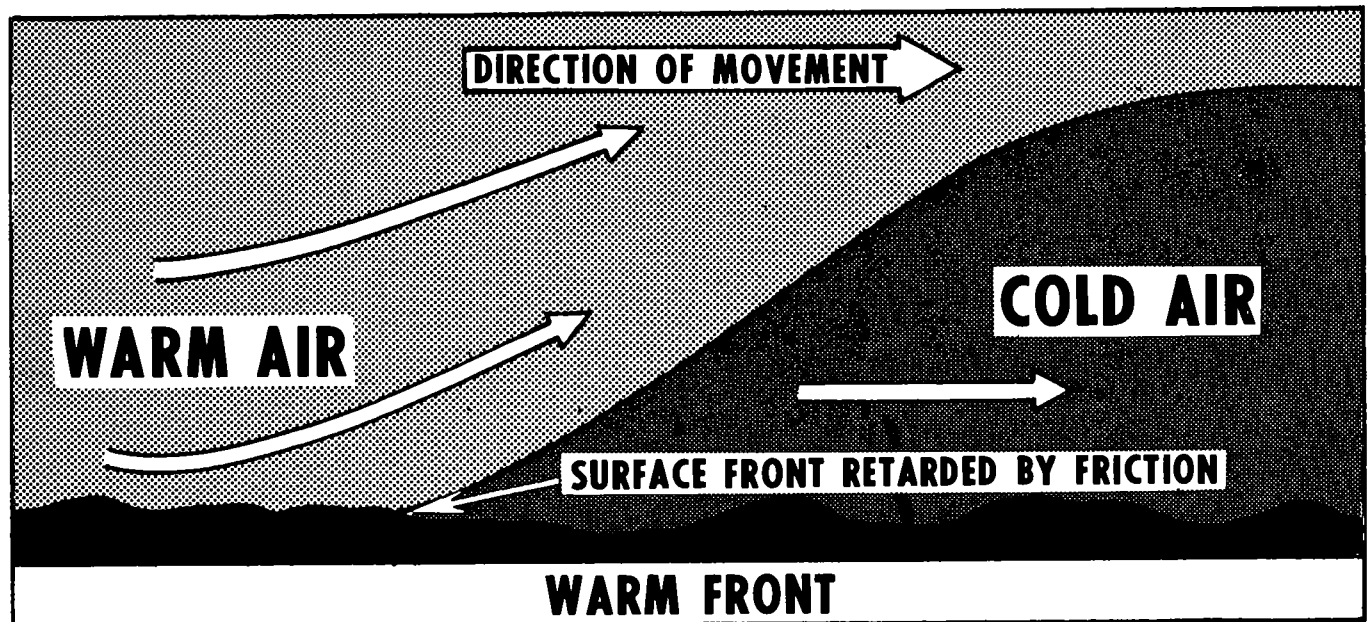
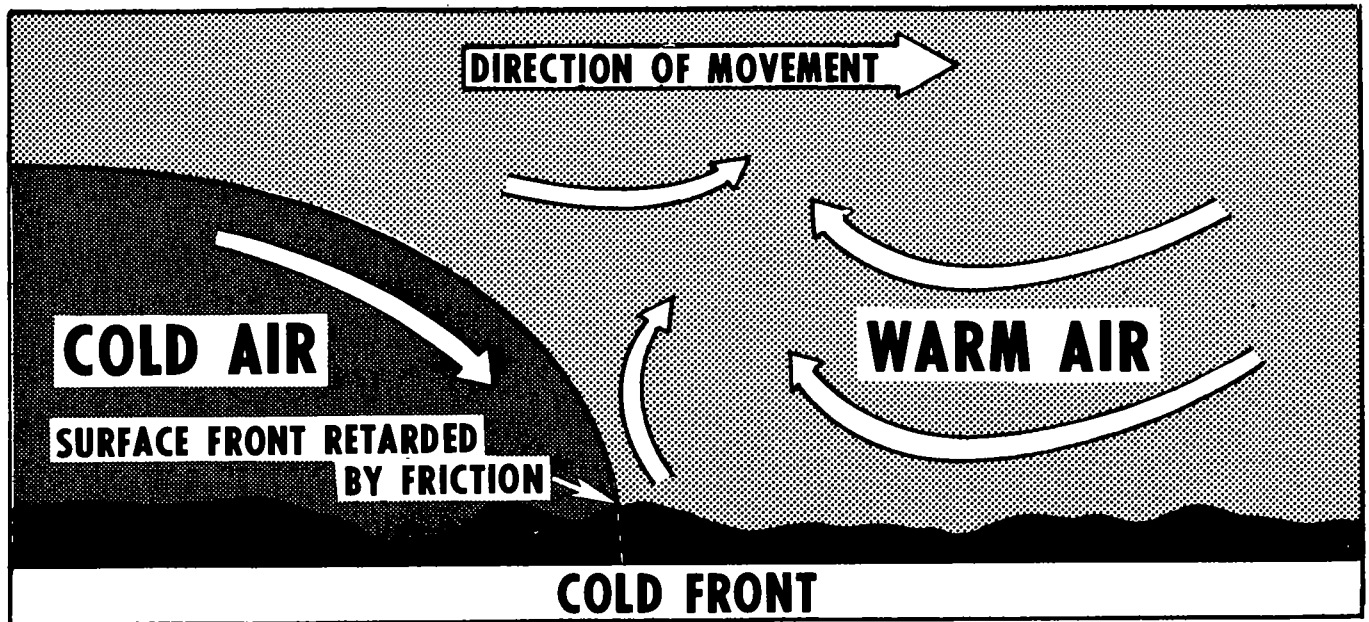
(2) *Water vapor content*. The moisture content of the air mass being lifted by the frontal surface and the height to which the moist air is lifted determine whether clouds will form in the warm air. Clouds along all fronts are initially produced by expansional cooling as the warm air is lifted above the frontal surface. Clouds will form only when the air cools enough to lower the temperature to the dew point. In locations where the warm air has a continental source region, the lifting action may be insufficient to produce clouds ("dry" fronts).

(3) *Stability*. The stability of the displaced air also affects the degree of turbulence along a front. Unstable air will produce predominantly cumuliform clouds; stable air, stratiform clouds.

Note. Atmospheric stability is a function of the temperature lapse rate.

7-2. Air Mass Discontinuities

A front is a boundary in the atmosphere along which certain physical properties between the air masses are discontinuous. These discontinuities between air masses are used to identify a front and to determine its location both in the atmosphere and at the surface.



The slopes in the above fronts are exaggerated for diagrammatic purposes.

The scale below represents a true vertical scale of 1 to 100.

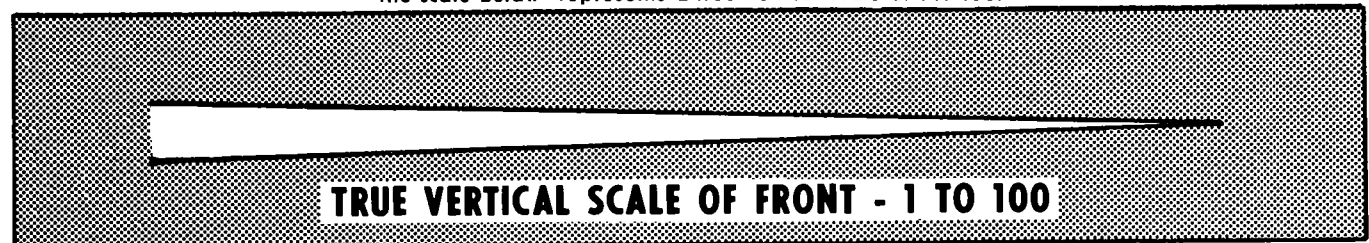


Figure 7-2. Vertical cross section showing frontal slopes.

a. *Temperature.* Temperature is one of the frontal surface discontinuities. Typical fronts consist of warm air above the frontal surface and cold air below it. A radiosonde observation through a frontal surface will often indicate the relatively narrow layer where the normal decrease of temperature with height is reversed. This temperature inversion is called a *frontal inversion* (fig 7-3), and its position indicates the height of the frontal surface over the particular station. The temperature increase within the inversion layer and the thickness of the layer can be used as a rough indication of the intensity of a front. Active fronts tend to have shallow inversion layers; weak fronts tend to have deep inversion layers.

b. *Wind.* The discontinuity of wind across a frontal boundary is primarily a change of wind direction. A *wind shift* refers to a change in the direction from which the wind is blowing. If the wind ahead of a front is southwesterly, it normally shifts to northwesterly after the front passes. Easterly winds usually become westerly. The speed of the wind is not always discontinuous across a front; however, wind speed frequently increases abruptly after the passage of a cold front, and decreases slightly after the passage of a warm front.

c. *Pressure Tendency.* Observing stations report pressure tendency (the rate at which surface pressure rises or falls) by *trend* (rising or falling) and by the *amount of change* during the 3 hours preceding the time of the report. Pressure tends to change regularly, in trend, with time; but when a frontal passage occurs, the change of pressure trend is abrupt and discontinuous. A falling pressure tendency gradually intensifies in amount with the approach of a front,

then rises abruptly or becomes steady after frontal passage. Thus, a moving front is characterized by a discontinuous pressure tendency. Although a stationary front also lies in a trough of low pressure (pressure increases with distance perpendicular to the surface front), the pressure tendency is continuous across the front; i.e., stations on both sides of the front report similar pressure tendencies over a 3-hour period.

d. *Dew Point.* The dew point can be used to determine the time of frontal passage at the surface or to locate the position of the frontal surface in the atmosphere. It may be a more reliable indicator than the free air temperature because the dew point is not directly affected by the daytime heating or nighttime cooling of the air. The dew point is relatively constant throughout the horizontal extent of an air mass, and therefore can be used to identify the arrival of a different air mass over a station.

7-3. Cold Fronts

a. *Generation of a Cold Front.* Frontal troughs normally extend from a closed area (center) of low pressure called a *cyclone* (fig 7-1). The term *cyclone* should not be confused with the term *tornado*. A tornado is a funnel-shaped cloud, whereas the cyclone is an area of counterclockwise winds (clockwise in the Southern Hemisphere) that often covers thousands of square miles. In the Northern Hemisphere, as the cyclones move from west to east across the Temperate Zone, the counterclockwise rotation of wind about the low-pressure center causes the polar air to advance southward on the back (west) side of the cyclone. The cold front is the leading edge of this

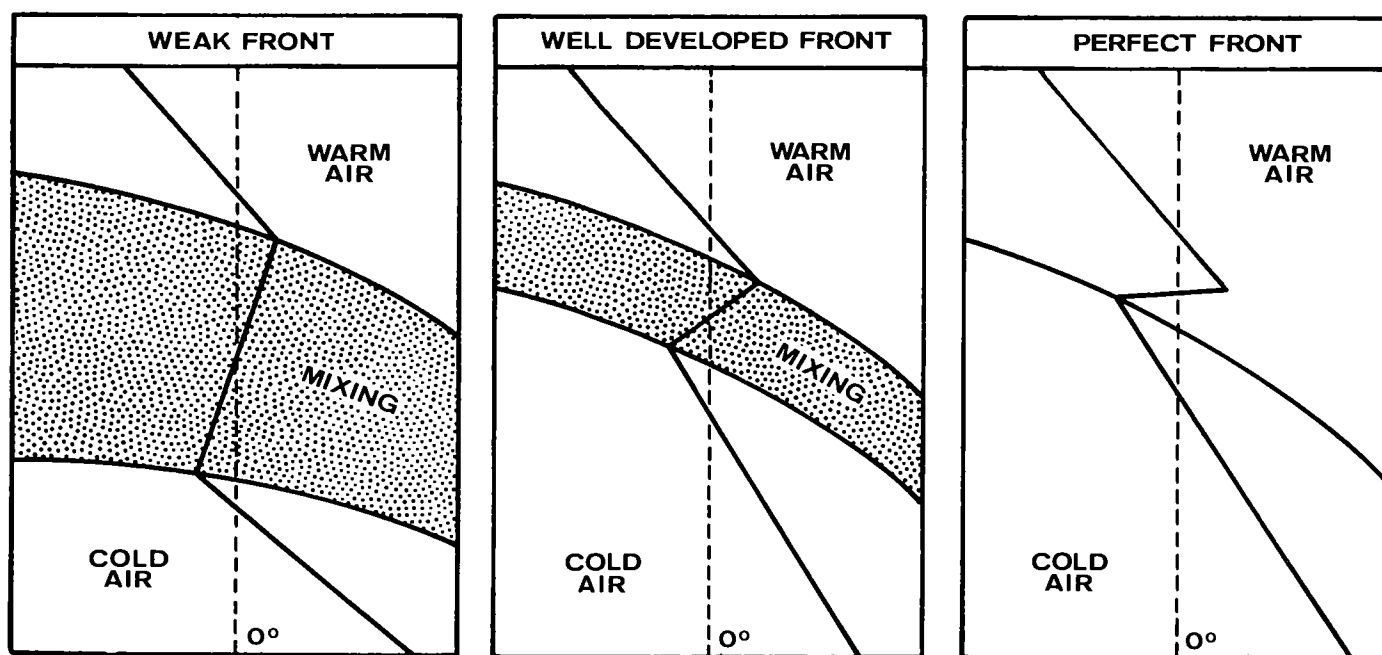


Figure 7-3. Temperature soundings through frontal surfaces.

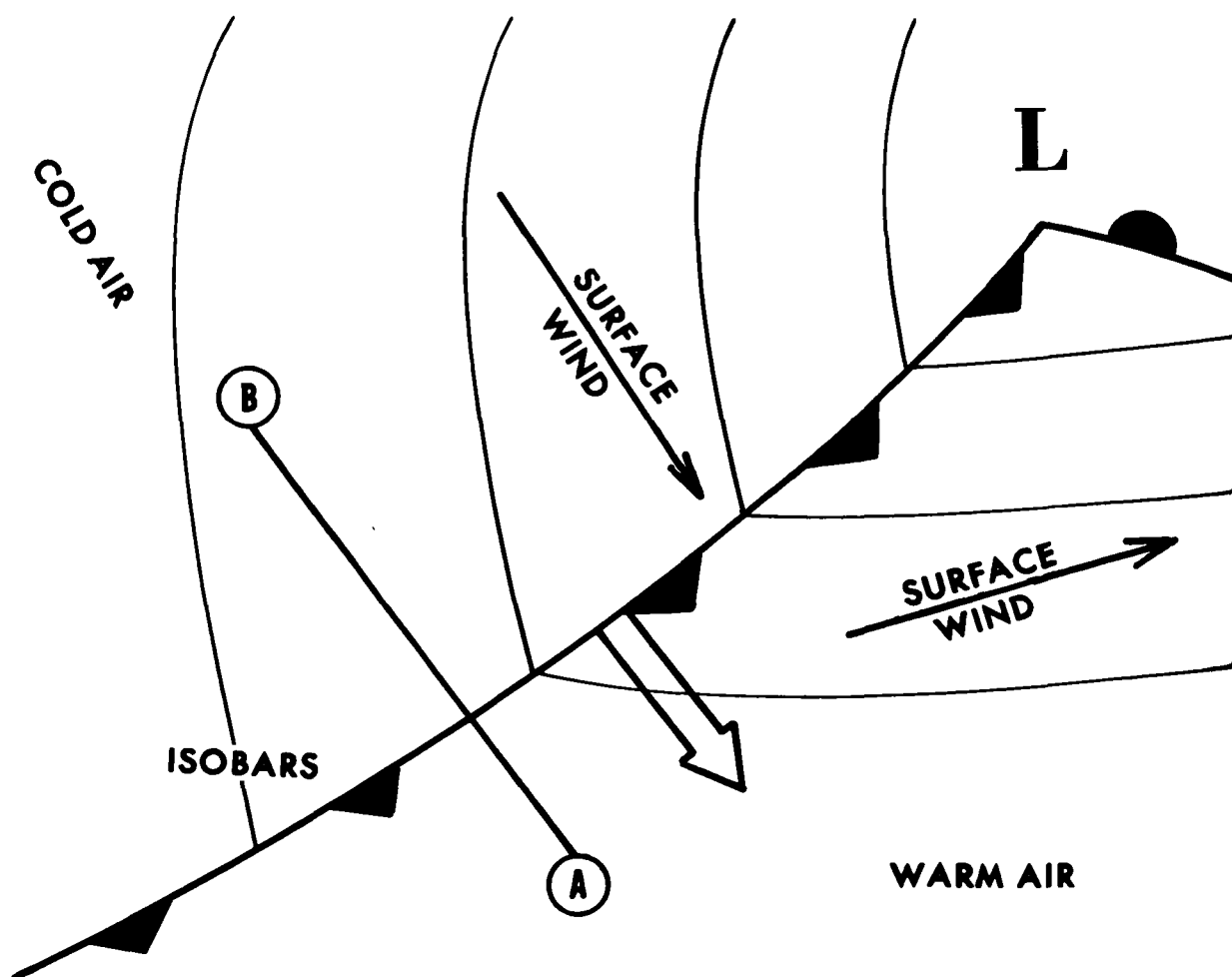


Figure 7-4. Cold front on surface weather map.

advancing mass of relatively cold air. Not all cyclones contain fronts; however, where a cold front does exist, it extends south-to-west from the center of lowest pressure.

b. Characteristics of a Cold Front. The characteristics of a typical cold front (fig 7-4) include—

(1) *Wind shift.* The wind in the warm sector ahead of the front is generally from the southwest quadrant of the compass rose, while the winds in the cold air mass behind the front are typically from the northwest quadrant of the compass rose.

(2) *Temperature distribution.* There is warm air ahead of the front in the southwesterly winds, and cold air behind the front in the northwesterly winds.

(3) *Cloud formations.* When the warm air ahead of the front is moist and unstable, the clouds are predominantly cumuliform. With typical cold fronts, a line of thunderstorms develops along the surface front and may extend for hundreds of miles. The typical weather band varies in width from 50 to 100 miles. The degree of instability, the moisture content of the warm air, and the speed and slope of the frontal surface determine the intensity and type of

frontal clouds. The *typical cold front* in the United States has cumuliform clouds arranged as shown in figure 7-5. However, if the warm air ahead of the front is moist and stable and the slope of the frontal surface is shallow, a deck of stratiform clouds may persist many hours after frontal passage. When cold fronts move *rapidly* into moist unstable air, pre-frontal squall lines may form up to 300 miles ahead of the surface front.

(4) *Direction of movement and speed.* Cold fronts generally move from northwest to southeast at an average speed of 22 knots (fig 7-4). This movement produces an average frontal surface slope ratio of 1 to 80 (fig 7-5).

(5) *Dew point change.* The cold air behind a cold front may be a continental air mass with a low dew point whereas the warm air ahead of a cold front may be maritime with a high dew point. Even in exceptional temperature situations, a distinct dew point change should still occur across a front.

c. Cold Front Identification on the Weather Map. Cold fronts are identified by a solid blue line on colored weather maps or by a series of black triangles

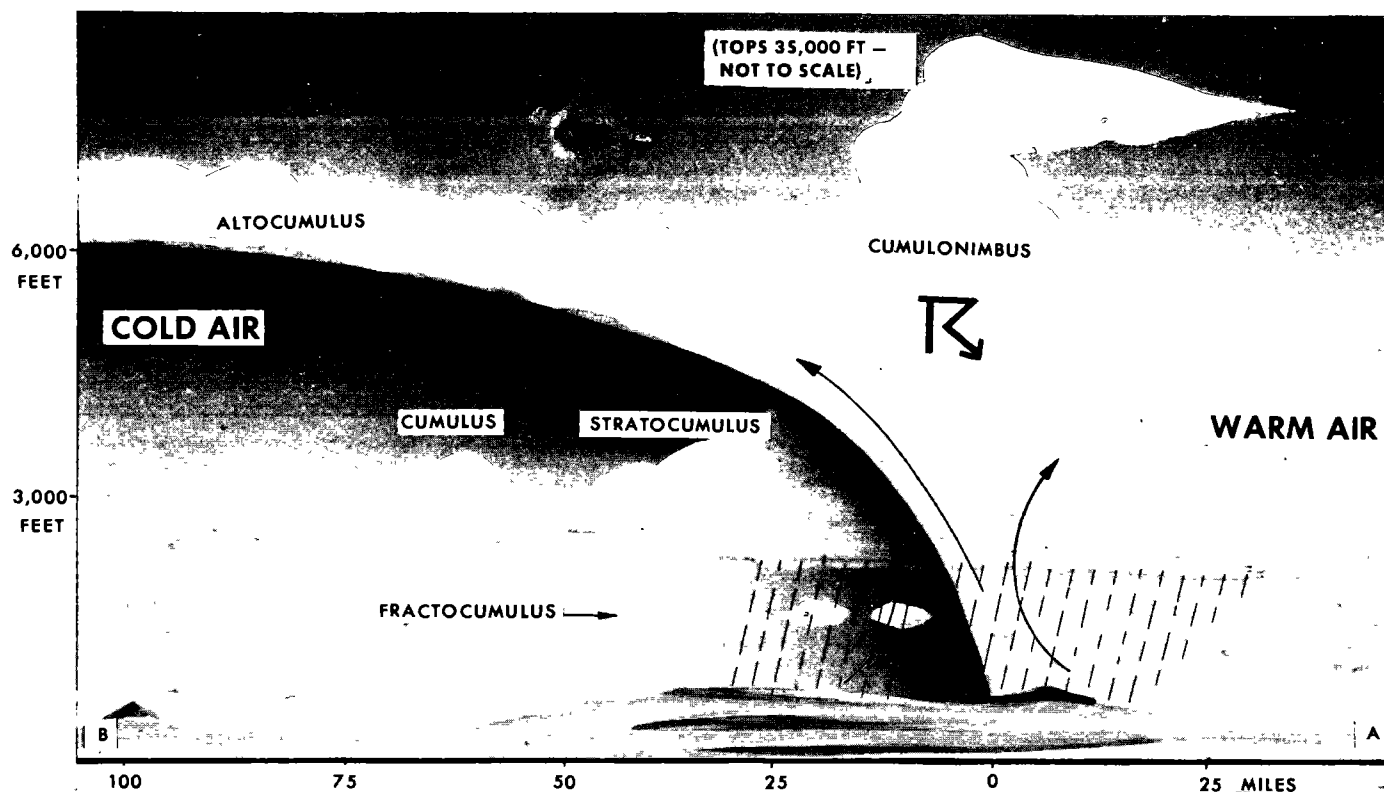


Figure 7-5. Typical cold front cloud formation.

along a black line on the facsimile weather map. The cold front moves in the direction toward which the triangles are pointing (fig 7-1 and 7-4).

d. Flight Procedures in Cold Front Weather. The chief hazards to aircraft flying in the vicinity of a cold front are caused by the solid line of cumuliform clouds along the front or a prefrontal squall line several miles ahead of the front. These hazards include turbulence (which may be extreme), thunderstorms, lightning, heavy rain showers, tornadoes, hail, and clear (glaze) icing. An additional hazard, which has been a contributing factor in more Army aircraft accidents than any of the others, is the presence of strong, variable, gusty surface winds around and under the thunderstorms. The technique for flying in the vicinity of cold fronts is determined from the type of aircraft, aviator experience, intensity of frontal weather, and mission urgency. Flight procedures for Army aviators include the following:

(1) Because of the narrow weather band associated with the average cold front, aviators can frequently land and wait for the squall line to pass.

(2) If penetration of the front is necessary, it should be made at a 90° angle to the front. This will provide passage through the weather band in the shortest possible time.

(3) En route weather facilities (radar approach control (RAPCON), airways route traffic control centers (ARTCC), or METRO) should be contacted to

obtain latest information on the areas of least intensity in the squall line. The front should be penetrated at one of these "soft" points.

(4) Procedures for flight in turbulent air should be followed as established in the operator's manual (-10) for the particular aircraft. This *usually* states a reduced airspeed, a penetration altitude below 6,000 feet, and attitude instrument flying.

(5) Since no two fronts are exactly alike, each flight should be planned before takeoff to obtain maximum benefit from the weather briefing, including knowledge of the weather conditions of the particular front affecting the flight.

7-4. Warm Fronts

a. Generation of a Warm Front. Surface cool (polar) air retreats northward on the forward (east) side of cyclones in the Northern Hemisphere (fig 7-1). The air mass boundary formed between the trailing edge of the retreating mass of cool air and the warm air mass moving in to replace it is a warm front. Warm fronts lie in troughs of low pressure and normally extend eastward from a center of low barometric pressure (fig 7-6).

b. Characteristics of a Warm Front. The characteristics of a typical warm front include—

(1) *Wind shift.* The wind in the cool polar air ahead of the typical warm front is from the southeast

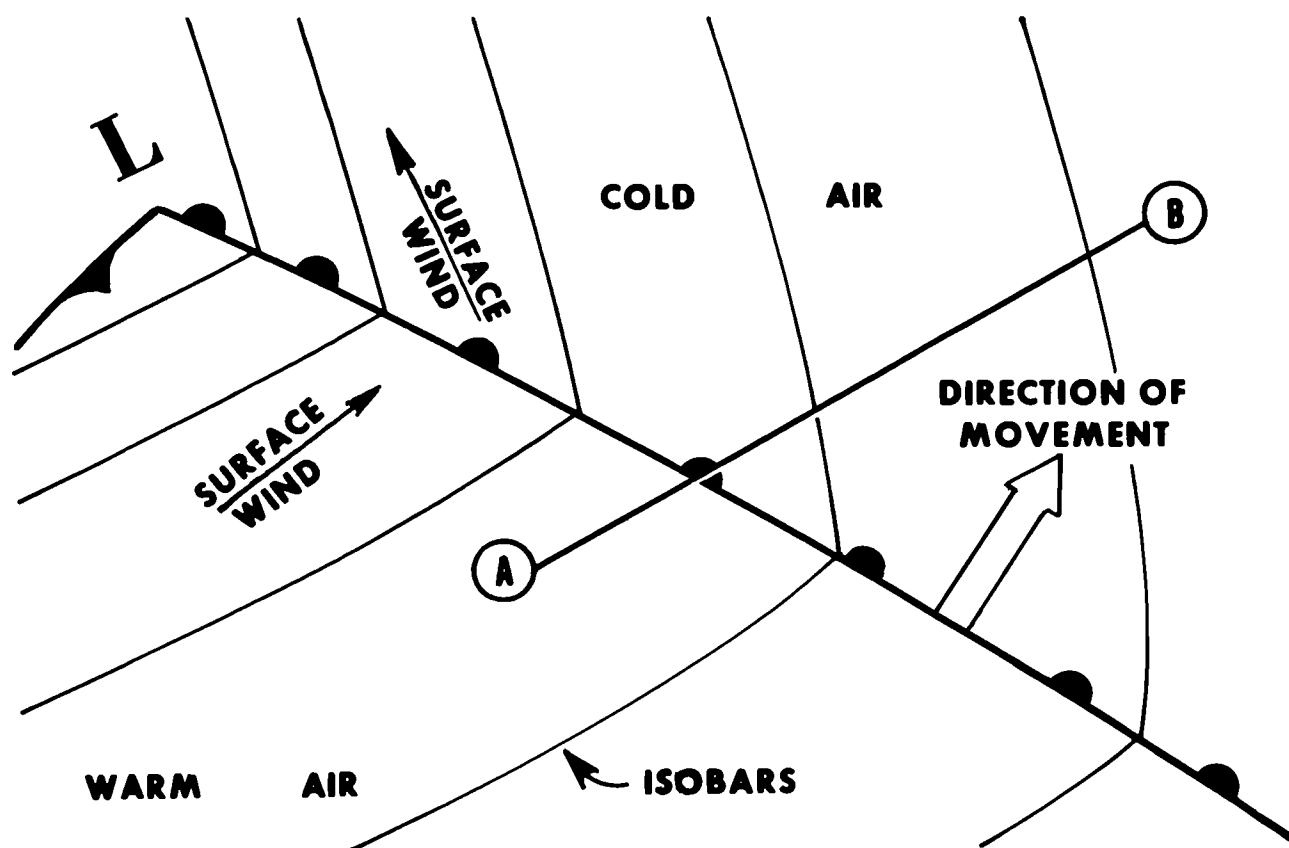


Figure 7-6. Warm front on surface weather map.

quadrant of the compass rose, while the wind in the warm sector behind the front is from the southwest quadrant.

Note. The warm sector is the area of warm southerly winds between the cold front and the warm front at the surface. Therefore, the same wind pattern usually exists "ahead" of the cold front that exists "behind" the warm front; i.e., it is the same tropical air mass. "Behind" refers to conditions that will exist after the surface front has passed a location on the earth. "Ahead" refers to conditions that exist before a surface front arrives at a place on the earth. Northwest winds, decreasing temperatures and dew points, and rising pressure exist "behind" a typical cold front (fig 7-4). Southwest winds, higher temperatures and dew points, and rising or steady pressure exist "behind" a typical warm front (fig 7-6).

(2) *Temperature change.* As a surface warm front passes a location the temperature increases, but the amount of increase varies from a few degrees to more than 20° F.

(3) *Cloud formation.* As the warm southwesterly winds behind the front converge with the cool southeasterly winds ahead of the front, the lighter advancing warm air will glide up over the retreating wedge of cold air (fig 7-2). If the warm air is lifted above the

condensation level, clouds will form in the warm air above the frontal surface. When the warm air is moist and stable, the clouds will be stratiform, ranging from thick nimbostratus near the surface front to high cirrus as far as 1,000 miles ahead of the front. The typical cloud pattern is shown in figure 7-7. Normally an area of rain extends 300 miles ahead of the front. As the rain evaporates in the thin wedge of cold air, this air becomes saturated and produces an area of low stratus or fog about 100 miles wide ahead of the surface front. The prefrontal fog may cover hundreds of square miles, with ceilings and visibilities below minimums. During the winter months, two distinct freezing levels exist in the typical warm front cloud and precipitation areas (fig 7-8). During summer when the warm moist air is conditionally unstable, the stratiform overcast above the frontal surface may become impregnated with scattered thunderstorms, with higher bases than cold front thunderstorms and not aligned solidly as with a squall line. When cumuliform clouds occur in a warm front cloud pattern, possible heavy turbulence may be imbedded within the major cloud system. However, the *typical warm front* is characterized by a wide area of stratiform clouds with low ceilings and poor visibilities (fig 7-7).

(4) *Direction of movement.* Warm fronts usually

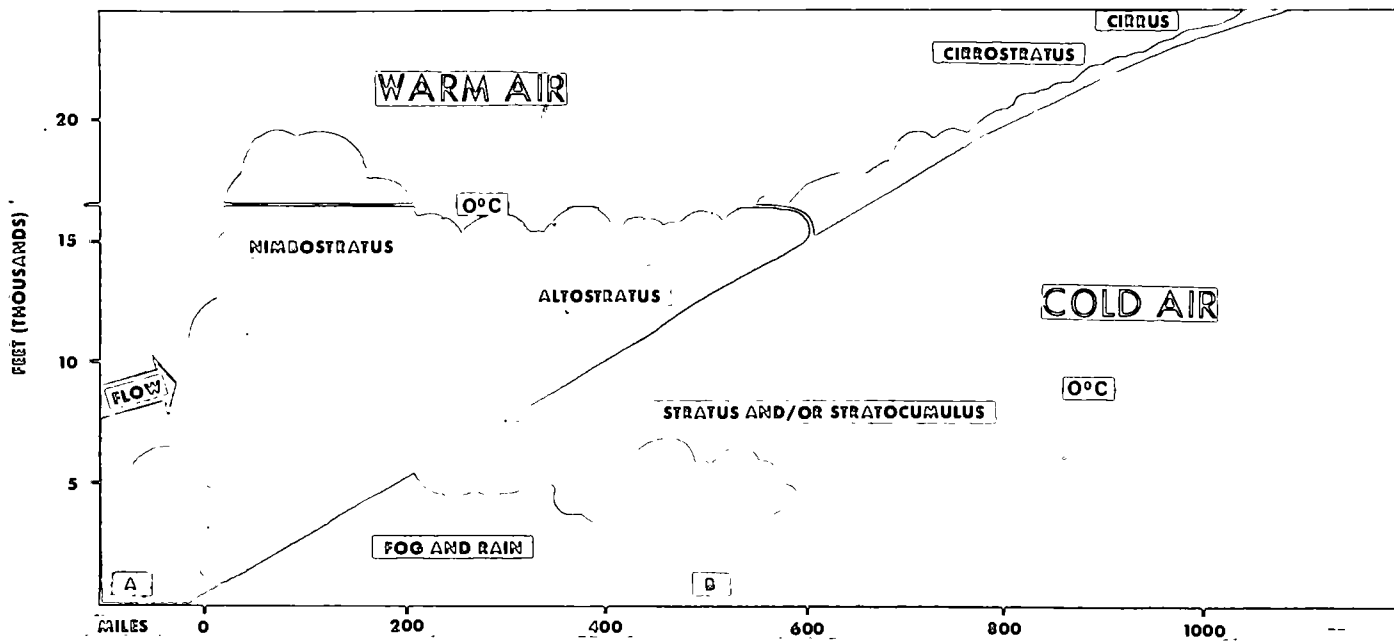


Figure 7-7. Typical warm front cloud formation.

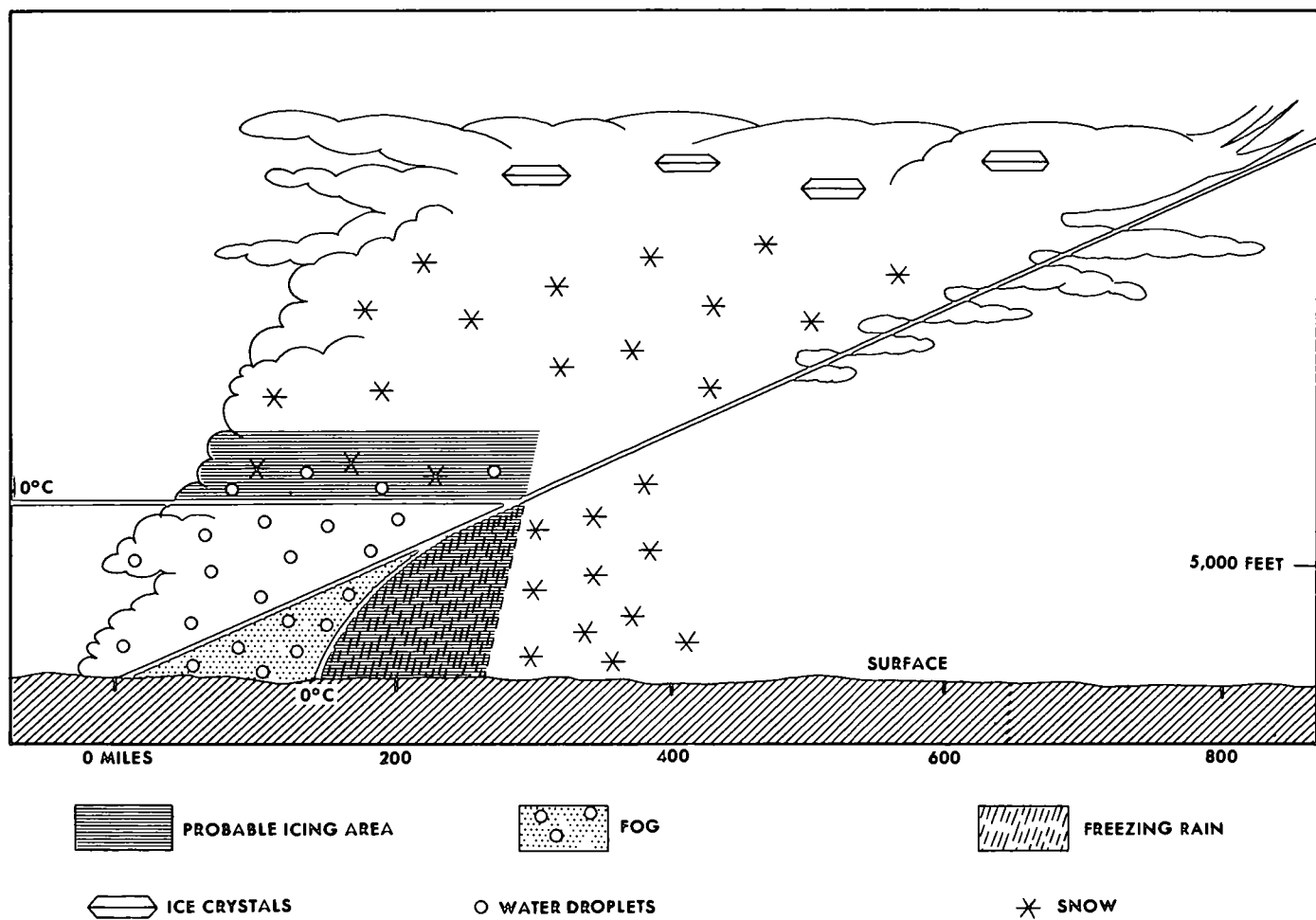


Figure 7-8. Probable icing zones in a warm front.

move from southwest to northeast at an average speed of 10 knots. This direction of motion is a combination of—

The surface wind movement in the cool air mass, usually from southeast to northwest, and

The movement of the entire pressure system from west to east.

(5) *Speed and slope.* The slow speed of a warm front is a result of opposing wind components—the surface winds in the cool polar air have an easterly (east to west) component, while the entire pressure system is moving from west to east. The cold front, by contrast, moves much more rapidly than the warm front because both the surface winds in the cold polar air and the movement of the entire cyclone have a west to east component. The average slope ratio of the warm frontal surface is 1 to 200 (fig 7-7).

c. Warm Front Identification on the Weather Map. Warm fronts are identified by solid red lines on colored weather maps and by a series of black semicircles along a black line on the facsimile weather map. The warm front moves in the direction toward which the semicircles are pointing (fig 7-1 and 7-6).

d. Flight Procedures in Warm Front Weather. The chief hazard to flight in most warm frontal areas is the wide overcast area with low ceilings and poor visibility ahead of the front. The first sign of an approaching warm front is the thickening of cirrostratus clouds in the west. When flying toward the front from the cold air side, the aviator will observe the base of the cirrostratus lowering to form a thicker altostratus overcast. Approximately 300 miles ahead of the surface front, rain falling from the thick altostratus clouds and evaporating in the wedge of cold air below the frontal surface saturates the cold air. An area of lower clouds (usually stratocumulus) begins to form in the saturated cold air mass. As the rain becomes heavier, the stratocumulus cloud deck becomes more solid. Gradually the upper and lower cloud decks merge and form a solid cloud layer which may be over 15,000 feet thick. Rain and fog may reduce ceiling and surface visibility to zero for 200 miles or more ahead of the front. As the warm front approaches a surface station, the cloud bases continue to lower, with increasing restriction to visibility. Thunderstorms during the warm months of the year and severe icing during the winter are further hazards. The Army aviator should use the following procedures to combat warm frontal hazards:

(1) Warm frontal areas should be crossed either above the cloud tops or below the bases to avoid inadvertent entry into the turbulence of hidden thunderstorms which may exist at intermediate flight levels.

(2) If the flight destination is in an area dominated by warm front weather, an alternate should be

selected, either behind the front or as far as practicable ahead of the surface front, to avoid the area of low ceilings and poor visibility.

(3) A thorough weather briefing should be obtained before the flight to estimate the locations of turbulence, thunderstorms and icing conditions. METRO, RAPCON, or ARTCC's should be contacted (para 7-3d (3)) to obtain inflight data. Severe hazard areas should be avoided ((5) below).

(4) Upon encountering an area of freezing rain that produces severe glaze icing, the aviator should immediately climb above the frontal inversion.

(5) Areas of icing in clouds should be avoided, either by climbing to a higher altitude containing ice crystals and snow, or by descending into warmer air nearer the surface. Since, however, it is possible for two freezing levels to occur with the winter warm front (fig 7-8), freezing-level altitudes and flight altitude temperatures should be obtained during the weather briefing.

7-5. Occluded Fronts

a. Development of Occlusions. Successive stages in the development of an occluded wave are shown in (A), (B), (C), and (D) of figure 7-9. Figure 7-9 (B) depicts an *open wave*—a cyclone which includes a warm and a cold front. A cold front moves eastward more rapidly than a warm front. The cold front first overtakes the warm front at the crest of the open wave, and the wave gradually closes like the hands of a clock. As this closing of the warm and cold fronts occurs, the air of the warm sector is lifted off the surface. This is called the *occlusion* process ((D) of fig 7-9, and 7-10). The portion of the surface front, where the cold front has overtaken the warm front, is called a *surface occluded front* (fig 7-10).

b. Relationship of Cold and Warm Front Occlusions. The type of occlusion, cold front or warm front, depends upon the temperature distribution of the colder (polar) air masses north of the fronts. In cyclones over land, generally the coldest air mass is *behind* a cold front, but in coastal regions the air temperature *ahead* of a warm front may be colder than that behind a cold front. If the cyclone illustrated in (C) of figure 7-9 were located on the west coast of the United States during the winter, the air temperature behind the cold front would be moderated by its trajectory over the Pacific Ocean. The air mass boundary would still be a cold front, however, because polar air moving southward would be displacing warmer tropical air. Ahead of a warm front, the continental polar air moving over the northern Rocky Mountains would be very cold during the winter, actually colder than the air behind the cold front. However, the trailing edge of this retreating mass of very cold air would be a warm front, since

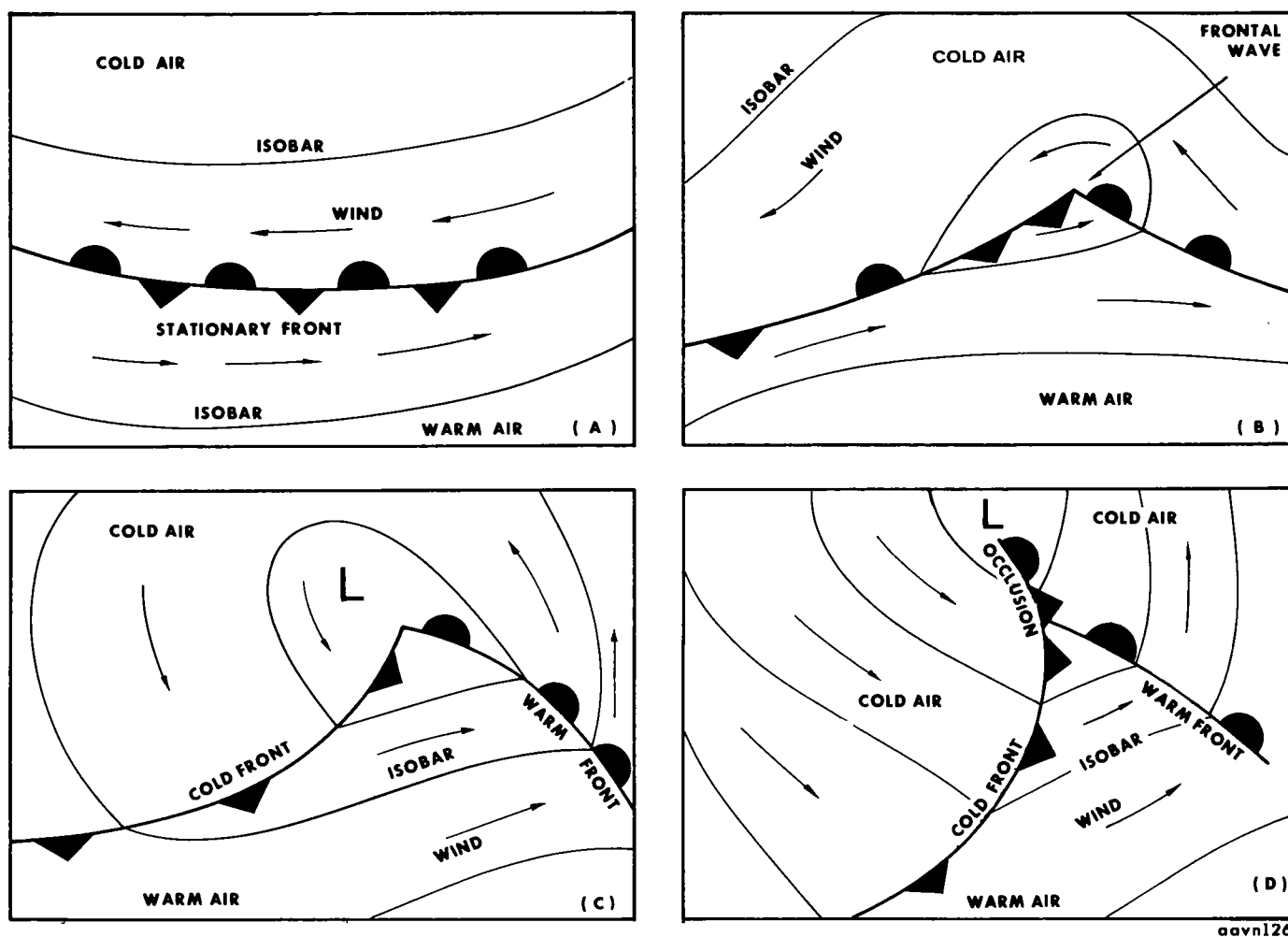


Figure 7-9. Stages in the development of the occluded wave.

the warm tropical air moving in is replacing the retreating polar air mass.

(1) *Cold front occlusions.* If the air behind the cold front is colder than the air ahead of the warm front in the occlusion process (fig 7-11), the cold front of the open wave will remain on the surface and displace both the warm sector air and the surface warm front. As the process continues, the surface warm front of the open wave becomes an *upper front* (no longer in contact with the surface). The upper warm front is so close to the surface occluded front that the symbol for the upper warm front is normally omitted from the surface weather map (fig 7-1 and 7-12). The *cold front occlusion* is named from the cold front which remained at the surface. After a cold front occlusion passes a station, temperature will decrease and the wind will become more northerly (fig 7-12).

(2) *Warm front occlusions.* If the air ahead of the warm front is colder than the air behind the cold front, the warm front of the open wave will remain on the surface and the occluding cold front will ride up over the warm frontal surface, becoming an *upper cold front* (*cold front aloft*) (fig 7-13). The warm sec-

tor air will be displaced from the ground by both frontal surfaces. The upper cold front is identified on the weather map by a series of open black triangles (fig 7-14) or by a dashed blue line on a colored map. It frequently precedes the surface occluded front by 200 to 300 miles. The *warm front occlusion* is named from the warm front of the open wave which remained at the surface. After the warm front occlusion passes a station, the temperature will increase slightly and the wind will gradually become more northerly.

c. Weather Associated With Occlusions. Typical weather and cloud patterns associated with occlusions are shown in figures 7-14 and 7-15. Occlusions combine the weather of the warm and cold fronts into one extensive system. The line of thunderstorms typical of a cold front merges with the low ceilings and poor visibility of the warm front. However, the two significant differences between the weather of the two types of occlusions are—

(1) The cloud system of the warm front occlusion is characteristically wider than that of the cold front occlusion because the warm frontal surface extends

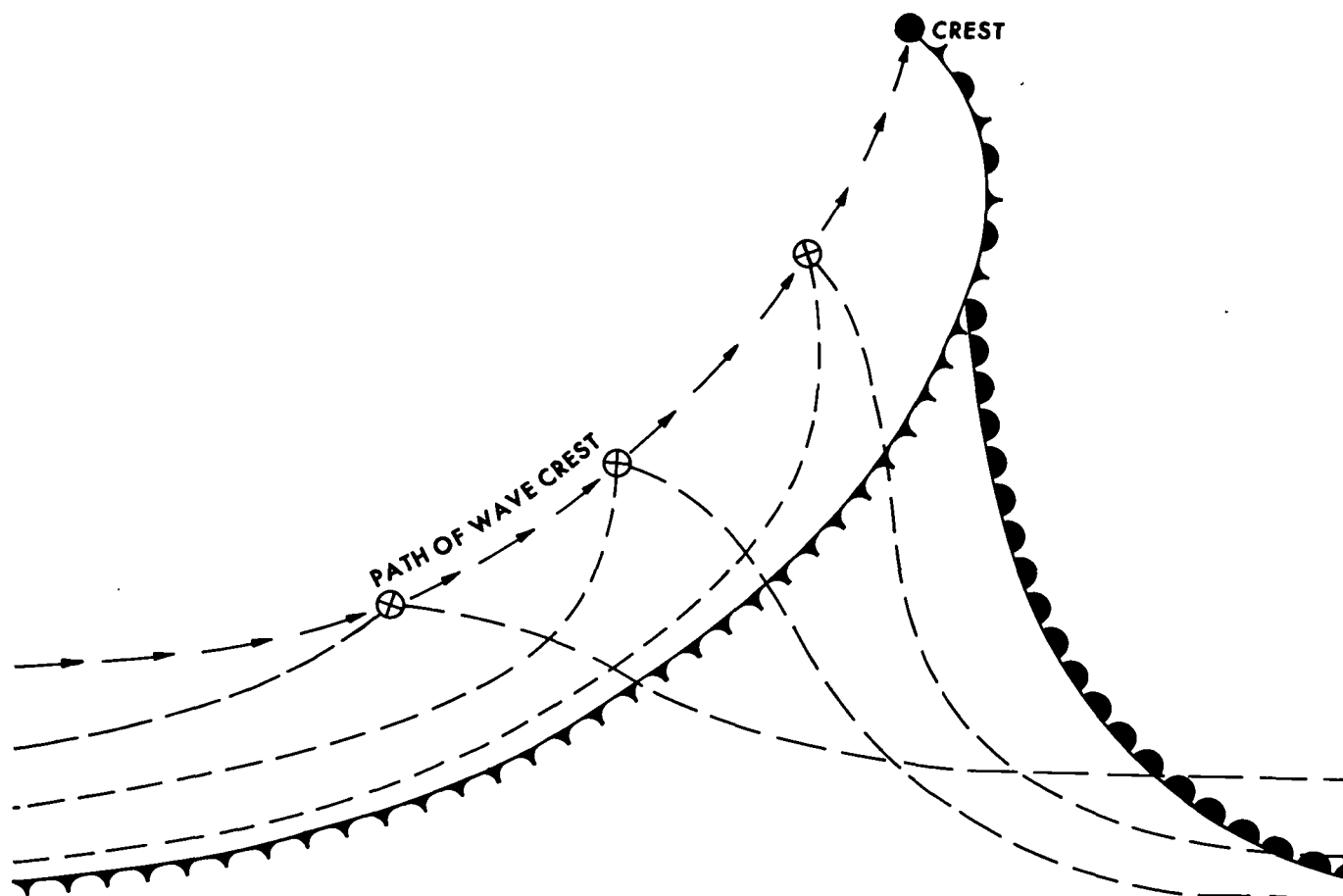
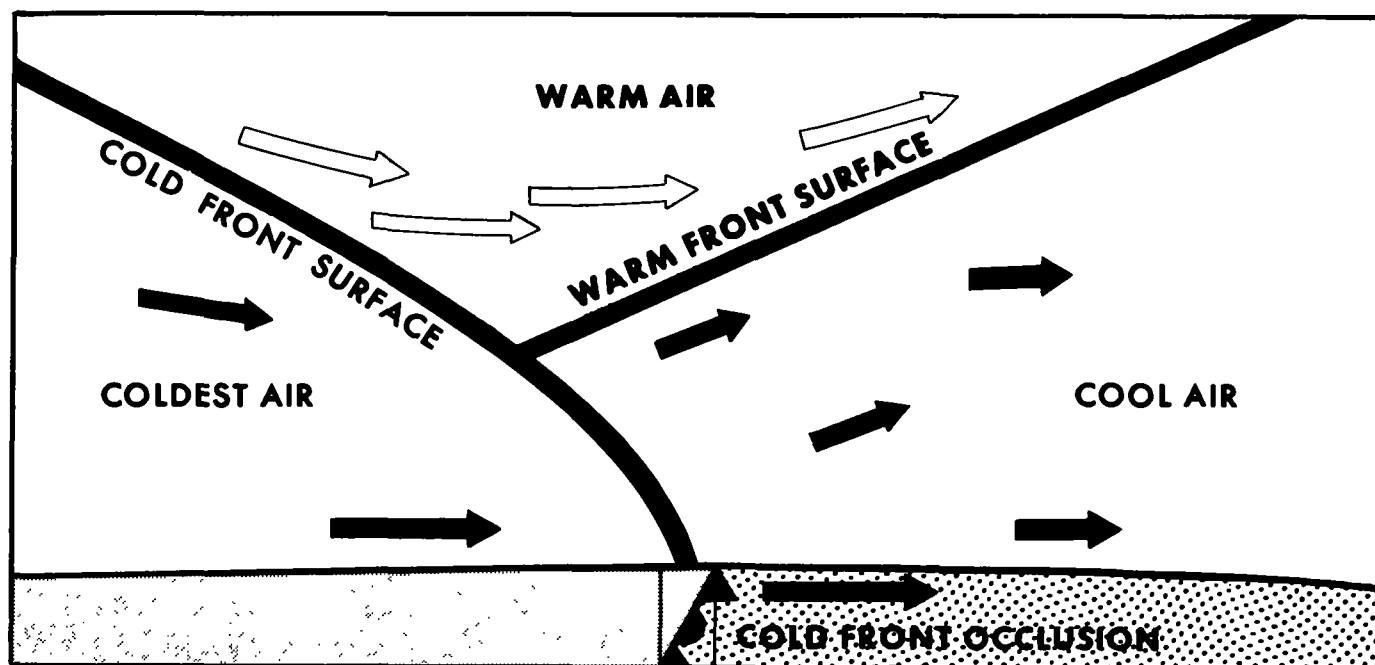


Figure 7-10. Wave development and occlusion.



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Figure 7-11. Cold front occlusion (vertical cross section).

under the upper cold front. This additional lifting surface extends under the upper cold front. This additional lifting surface between the upper cold front and the surface occluded front produces a region of nimbostratus or stratocumulus clouds not present with the cold front occlusion.

(2) Weather is most violent during the early stages of the occlusion along the upper front 50 to 100 miles north of the peak of the warm sector. The line of thunderstorms of the warm front occlusion is often imbedded within the overcast sky and may precede the surface occluded front by 200 to 300 miles. Thunderstorms of the cold front occlusion pass with the surface occluded front and may be visible from the air if approached from the west. Clearing skies often occur shortly after the passage of the surface cold front occlusion.

(3) Occluded frontal systems are more common in Northern than in Southern United States. Their greatest effect is felt during the winter months in both the northwest and northeast sections of the country.

d. Occluded Front Identification on the Weather Map. Map symbols are identical for the surface occluded fronts in both the warm and cold front occlusions. On the facsimile map, the symbol is an alternate triangle and semicircle on the same side of the black line. The symbols point in the direction of frontal movement. On the colored map, the surface occluded front is shown as a solid purple line; however, the weather map shows an upper cold front with the warm front type of occlusion (fig 7-14). An

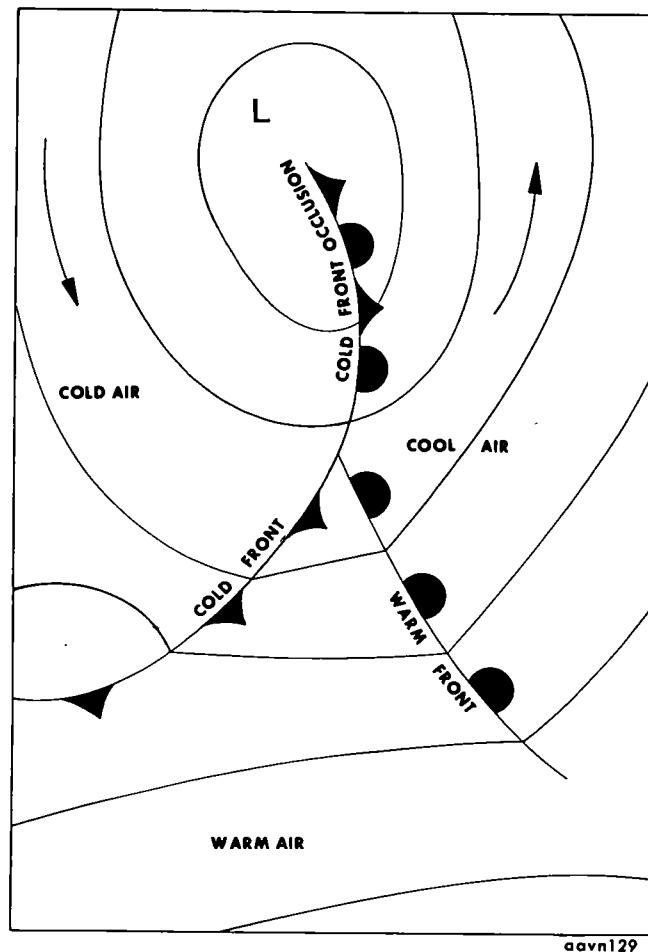


Figure 7-12. Cold front occlusion (surface map representation).

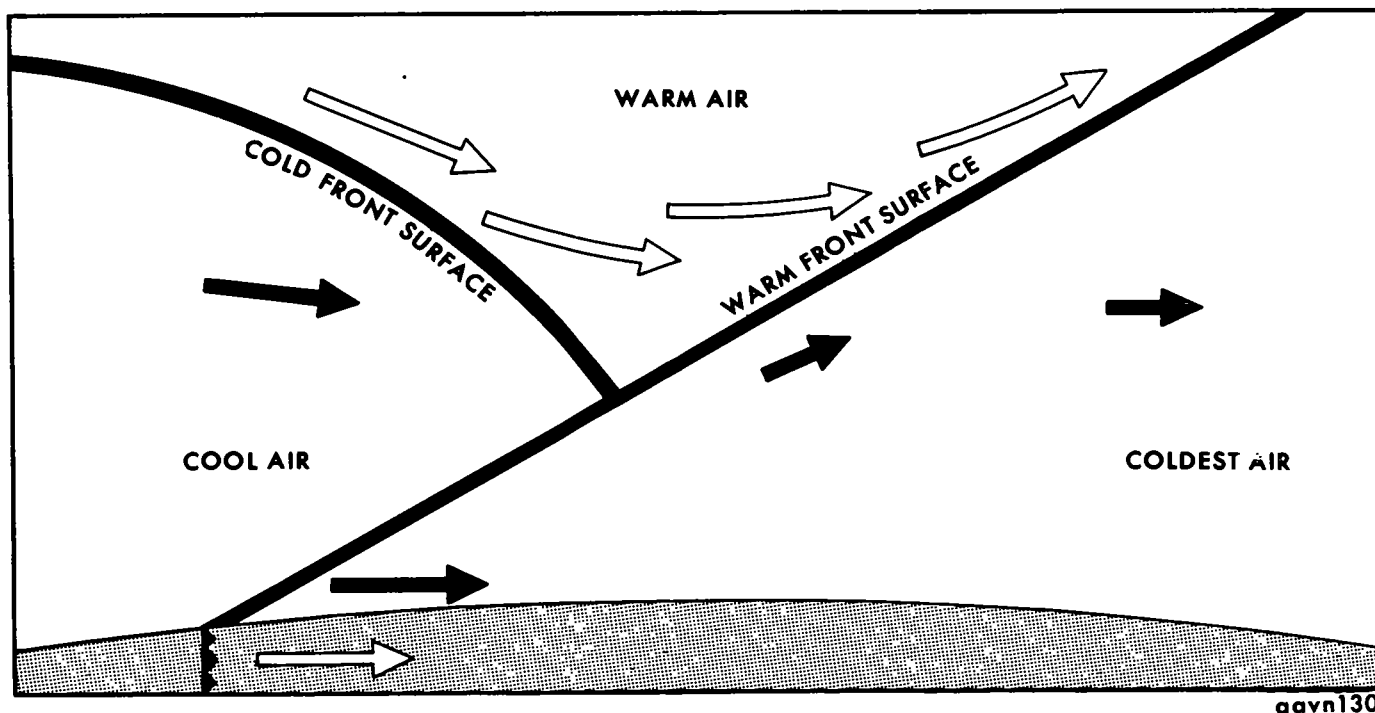
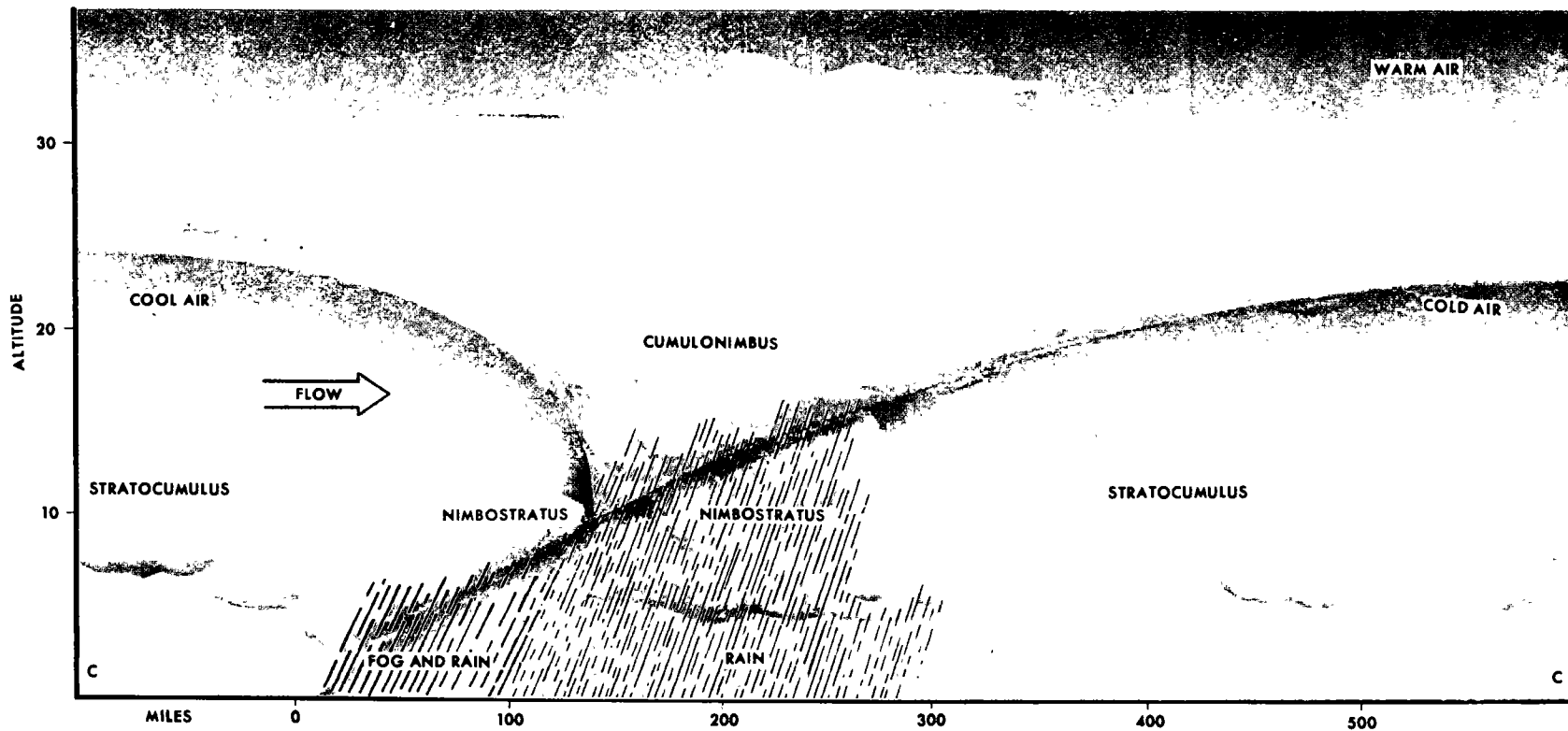


Figure 7-13. Warm front occlusion (vertical cross section).



THE CROSS SECTION OF THE WARM FRONT OCCLUSION SHOWN ABOVE OCCURS AT LINE CC ON THE WEATHER MAP AT THE RIGHT.

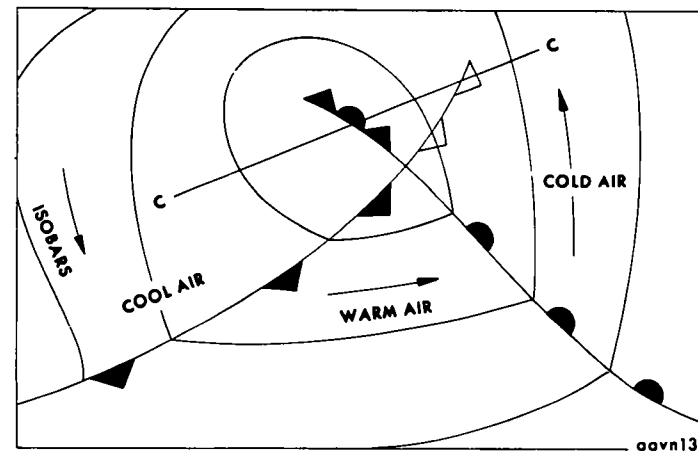


Figure 7-14. Warm front occlusion.

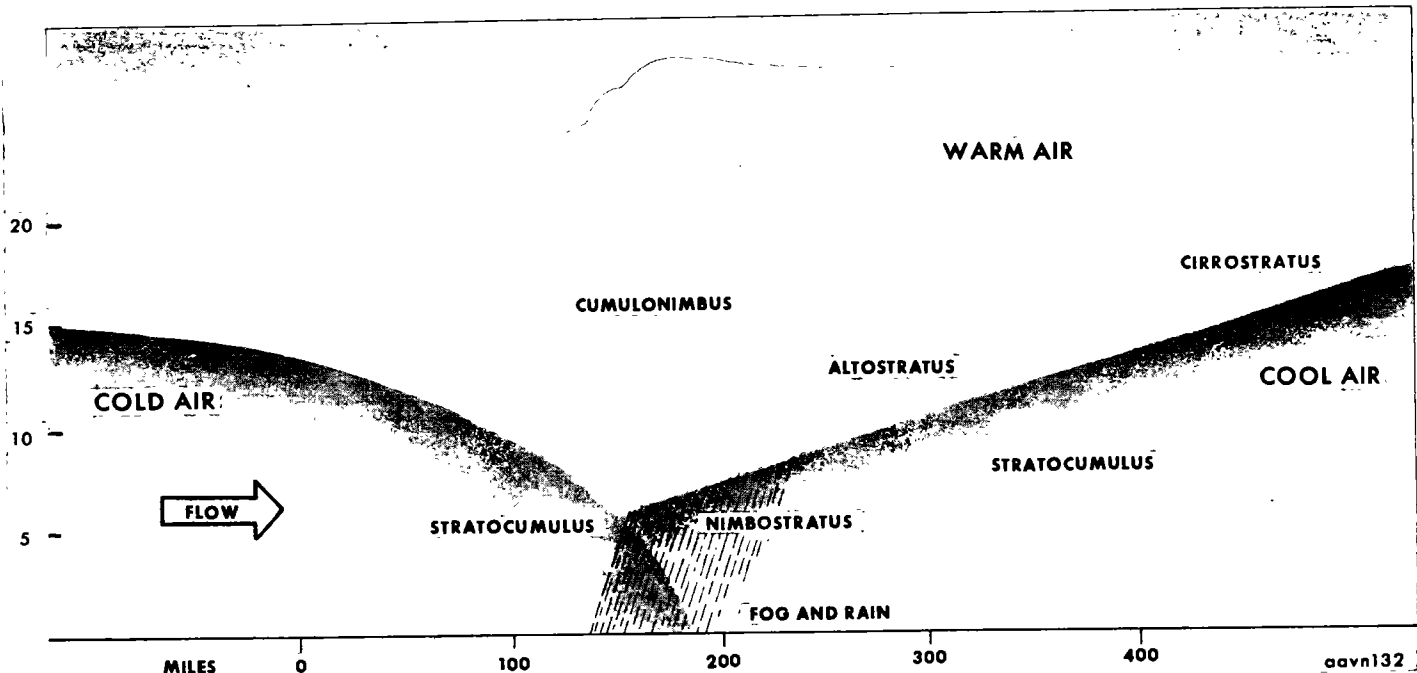


Figure 7-15. Cold front occlusion with associated weather.

upper warm front or (dashed red line or open black semicircles) is seldom indicated on the map with a cold front occlusion.

e. Flight Procedures With Occluded Fronts. The weather within an occluded system combines flight problems of both the warm and the cold front. Special considerations include the following:

(1) The flight should be planned to avoid the area of severe weather extending 50 to 100 miles along the upper front north of the peak of the warm sector.

(2) Intermediate flight levels where hidden thunderstorms generally occur should be avoided. In Army aircraft, a low-level flight below 6,000 feet absolute altitude is generally recommended. While flying at low levels, the occurrence of heavy showers will indicate that stronger turbulence is present in the clouds above. Low-level flight under the clouds should be avoided where mountainous terrain is obscured by clouds, fog, or precipitation.

7-6. Stationary Fronts (Quasi-Stationary Fronts)

Although there is no movement of the surface position of the true stationary front, an upglide of air can occur along the frontal slope. The angle of this flow of air in relation to the surface position of the front and the strength of the upgliding wind control the inclination of the frontal slope (fig 7-16). Fronts moving less than 5 knots are called either *quasi-stationary* or *stationary*.

a. Warm Air. The warm air rising over the stationary frontal surface will cool adiabatically. If the

air is lifted above the condensation level, clouds will form above the frontal surface.

(1) If the upgliding air is stable and saturation occurs, stratiform clouds will form. Intermittent drizzle may occur and, if the air is lifted beyond the freezing level, icing conditions will exist. If the freezing level is fairly close to the ground, a mixture of drizzle, rain, and snow may appear over the area (fig 7-17).

(2) If the upgliding air is conditionally unstable and saturation occurs, predominantly cumuliform clouds will form (fig 7-18). The sky condition is often overcast, but the precipitation occurs as intermittent moderate to heavy showers with thunderstorm activity. Occasionally the thunderstorms may aline side by side to produce a line squall, but the typical cloud pattern is more similar to that of an unstable warm front.

b. Cold Air.

(1) Because of convergence of air across the isobars, the cold air below the frontal slope may also be rising near the surface position of the front. Cloudiness is less likely to form in the cold air since the humidity is usually low on this side of the front.

(2) Precipitation falling from the clouds that have formed above the frontal slope will partially evaporate while falling through the colder air below the frontal surface. The evaporation will cause the humidity to increase in the colder air. If saturation occurs at the surface, widespread frontal fog conditions will result. With strong winds, large frictional eddy currents near ground level will result in the formation of low-based clouds (fig 7-17 and 7-18).

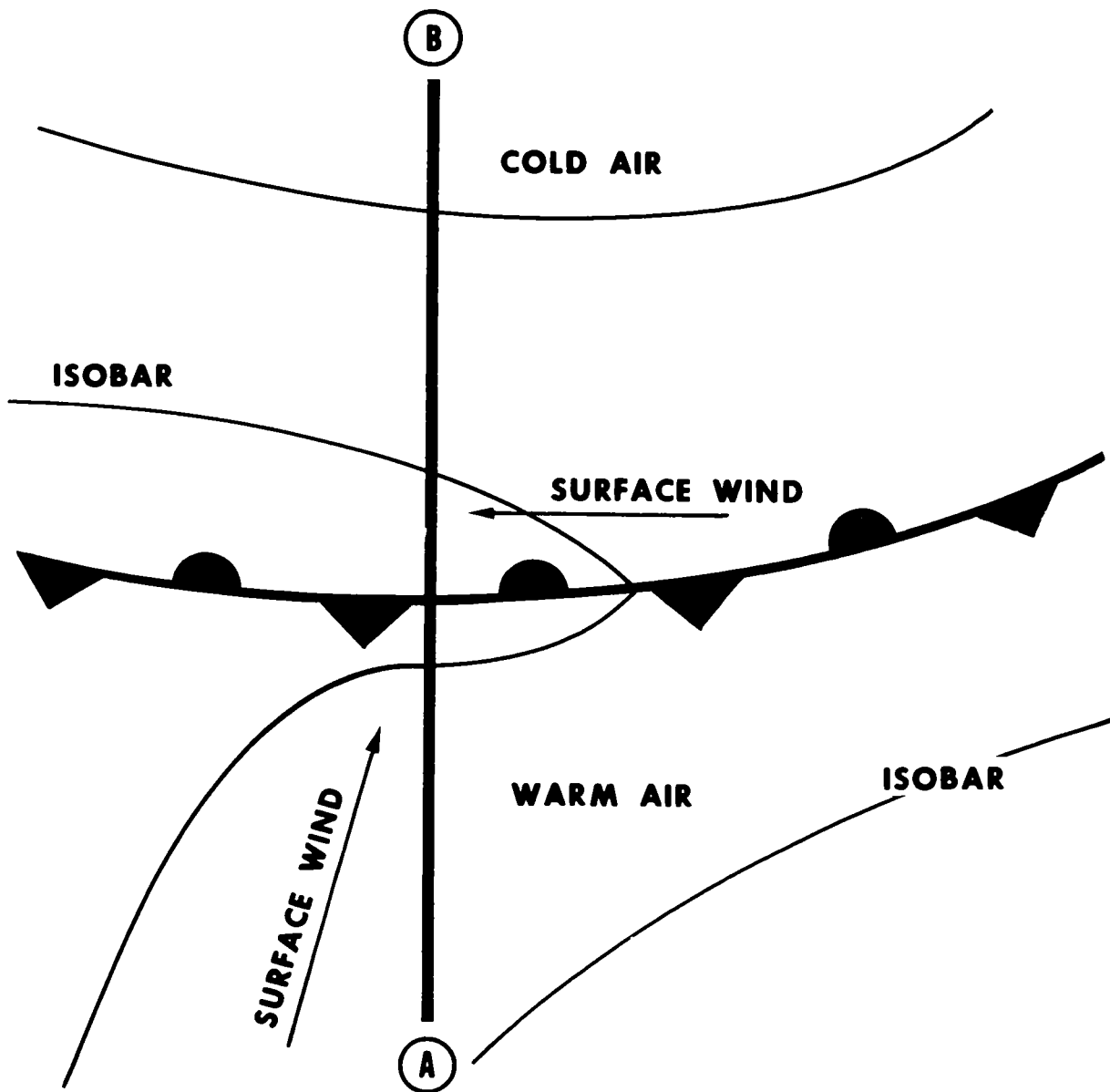
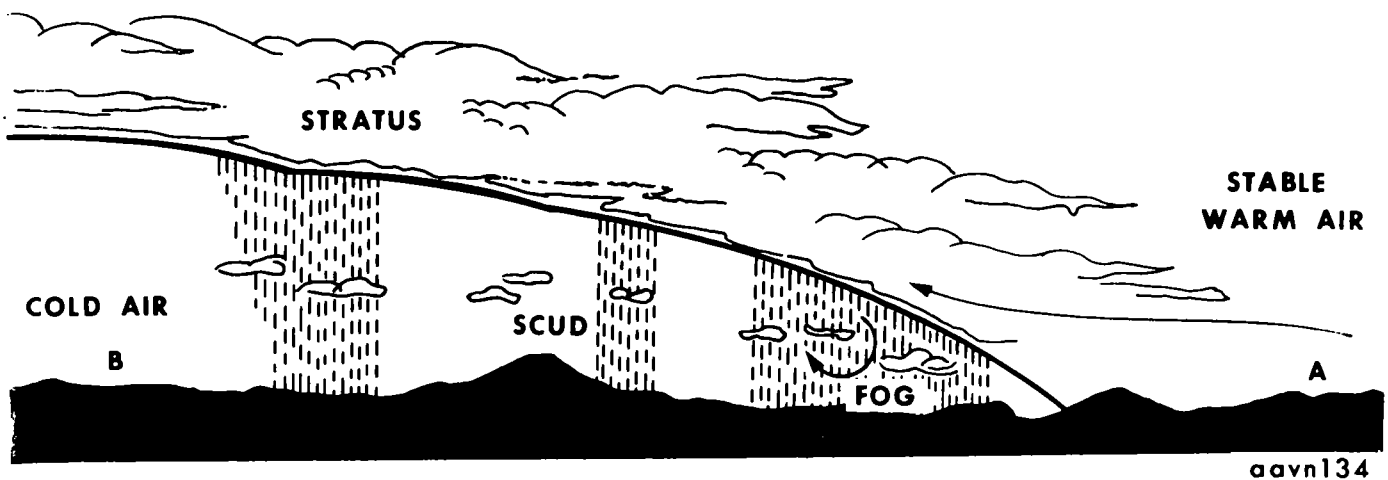


Figure 7-16. Stationary front as shown on a surface weather map.



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Figure 7-17. Stationary front with stable warm air.

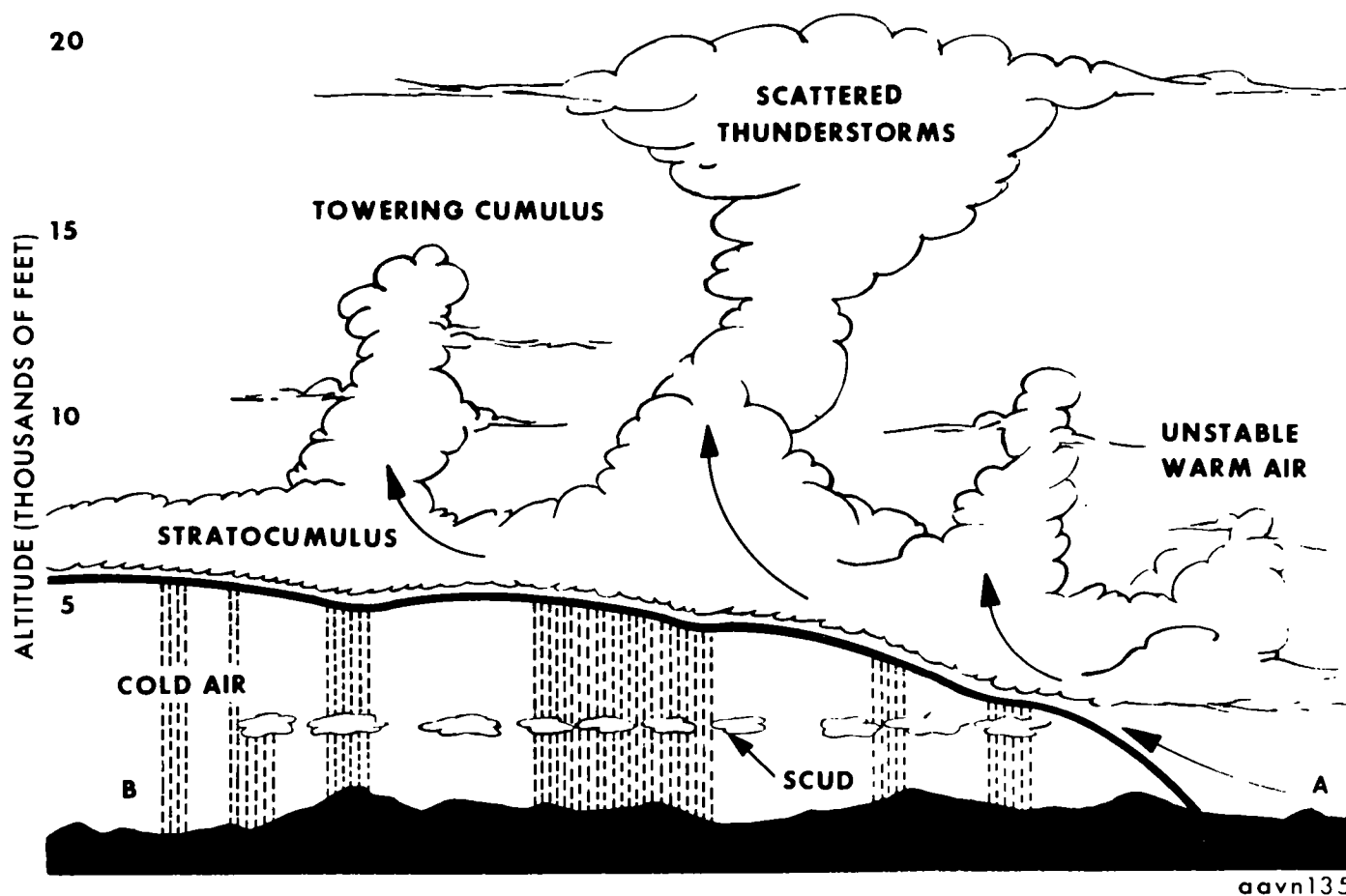


Figure 7-18. Stationary front with unstable warm air.

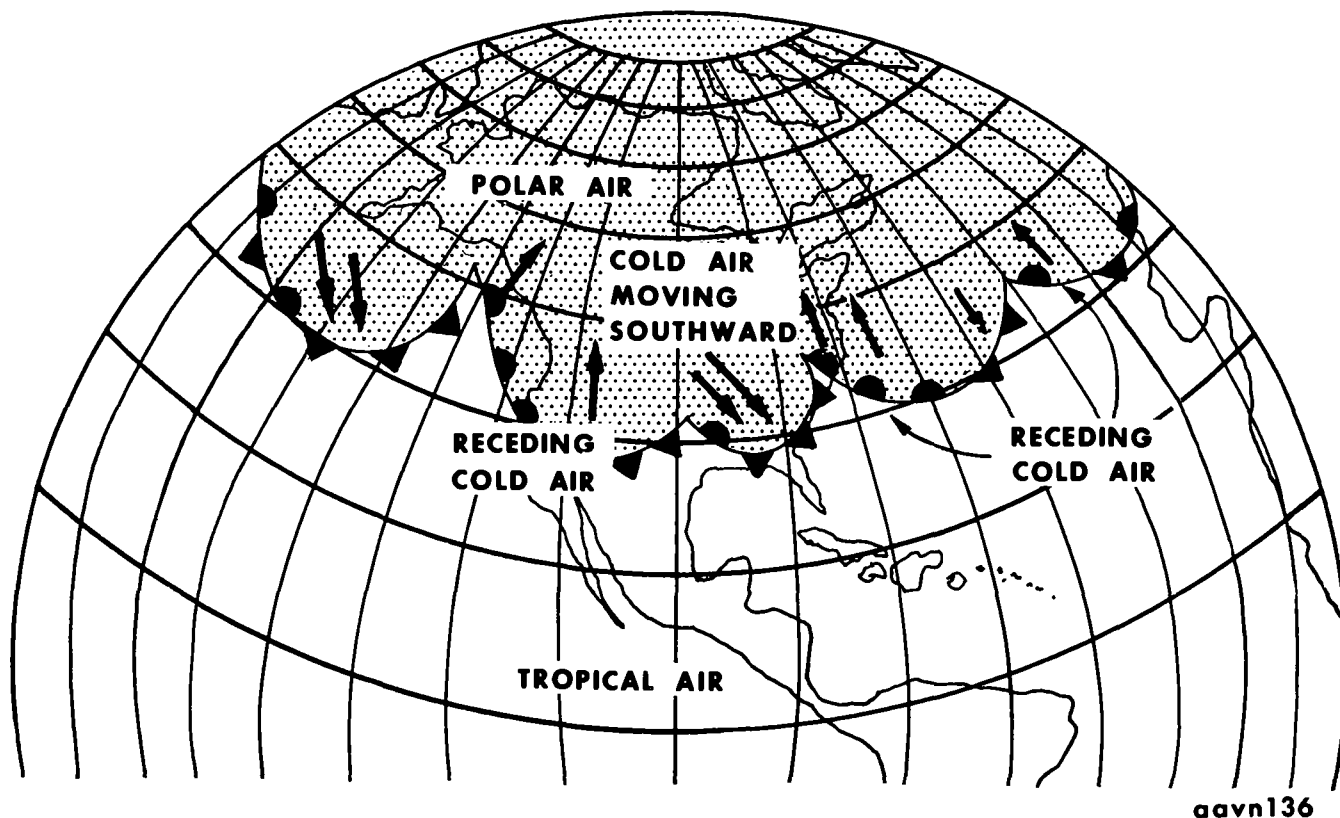
7-7. Cyclonic Wave Development

a. Fronts are air mass boundaries emanating from centers of low barometric pressure. To the meteorologist, any closed area of low barometric pressure is a *cyclone*. Not all cyclones have well-defined frontal waves. Those cyclones that do not contain fronts are relative lows, having their origin in the secondary circulation pattern; they are not caused by heating from the surface below them.

b. In the idealized general circulation pattern, a large cap of cold, dense air accumulates around the polar regions. This cold air is characterized by high pressure. The outer boundary of this high-pressure area is in the vicinity of 60° north latitude. Another general circulation belt of high pressure is centered in the vicinity of 30° north latitude, with its strongest centers over the Atlantic and Pacific Oceans. The outer perimeter of these oceanic high-pressure areas is also in the 60° north latitude region. Thus, the area around 60° north latitude is a belt of relatively low pressure. It is also a frontal region between the cold polar easterly winds moving clockwise about the polar high and the warmer prevailing westerly winds coming out of the high-pressure areas in the Tropics.

c. Ideally, this polar front and polar trough would remain in the 60° north latitude zone. In fact, outbreaks of cold polar air move southward across the Temperate Zones (fig 7-19). These *polar outbreaks* begin the cyclonic waves which move from west to east around the Temperate Zone (the secondary circulation). The outbreaks of polar air behind the outsurging polar front range in depth from a few thousand feet near the surface front to the upper troposphere hundreds of miles behind the surface front. Above this relatively shallow surface circulation, the west to east winds of the general circulation pattern continue to blow, moving the shallow secondary circulation below them.

d. Wind shear between the easterly winds of the cool air and the westerly winds of the warm air causes waves to form on the sloping surface of the polar front and make the front undulate. For example, if the front lies in an east-west direction, such a wave will cause one part of the frontal surface to bulge southward and another part northward. If the wind in the warm air is moving eastward, the bulges will move eastward as a wave. These waves are usually 200 to 1,500 miles from crest to crest (fig 7-1).



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Figure 7-19. Polar front.

e. Cyclone formation can be understood by comparing stationary front activity to ocean waves.

(1) A wave in deep water far from shore is stable. The surface oscillates back and forth many times without great variation in the amplitude of the wave. As the wave approaches the shore, the distance becomes shorter from crest to crest and greater from trough to crest. The shorter the interval between crests, the higher the wave, until it becomes top-heavy and breaks. The wave was made unstable by the great increase in amplitude.

(2) Atmospheric waves become unstable in the same manner. Long stationary fronts become wavy because of wind shear and pressure variation across the atmospheric boundary. Thus, the stationary front may change into a series of alternate cold and warm fronts, with wave crests (apexes) being the dividing points between cold and warm fronts. The interconnecting troughs are areas where the front is stationary (fig 7-1). If the pressure about the apex becomes sufficiently low, a circular pressure pattern takes shape around the apex, producing a counter-

clockwise wind. A considerable amount of condensation occurs, and when sufficient latent heat of condensation is added to the air, the air rises and the atmospheric pressure at the crest of the wave is further reduced. The pressure gradient strengthens and the counterclockwise wind becomes stronger. The apex and its counterclockwise wind area is called a *cyclone*.

(3) The sideways movement of waves on a front is seldom stable. Once started, they tend to increase in amplitude (fig 7-6). Instead of many waves following each other in orderly series, each wave continues to grow and the apex becomes deeper, so that the front never settles back to its original position (fig 7-7). The frontal wave breaks down in a manner similar to the breaking of surf; a large atmospheric whirlpool is created north of the frontal area. The fronts then dissipate due to equal temperatures and dew points across their boundary lines, or become stationary again in a new position south of their original location. If the frontal system does not dissipate, a new wave may form on the stationary front and go through a similar life cycle (*cyclogenesis*).



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CHAPTER 8

FOG

8-1. General

Fog is defined as minute droplets of water or ice crystals suspended in the atmosphere with no visible downward motion. It is similar to stratus clouds; however, the base of fog is at the earth's surface, whereas the base of a cloud is at least 50 feet above the surface. Fog may be distinguished from haze by its dampness and gray color. It is a serious hazard during takeoffs and landings because it restricts surface visibility. However, unlike other weather hazards, fog is of little concern during the en route portion of a flight. A knowledge of fog types and of fog formation and dissipation processes will enable the Army aviator to plan his flights more accurately.

8-2. Fog Formation

a. High Relative Humidity. A high relative humidity is of prime importance in the formation of fog since neither condensation nor sublimation will occur unless the relative humidity is near 100 percent. Thus, the natural conditions which bring about a high relative humidity (saturation) are also fog-producing processes (i.e., the evaporation of additional moisture into the air or cooling of the air to its dew point temperature). A high relative humidity can be estimated from hourly sequence reports by determining the spread (difference in degrees) between the temperature and dew point. Fog is rare when the spread is more than 4° F.; it is most frequent when the spread is less than 2° F.

b. Light Wind. A light wind is generally favorable for fog formation. It causes a gentle mixing action which spreads surface cooling through a deeper layer of air and increases the thickness of the fog. If calm winds exist when other factors are favorable for fog formation, only dew, frost (freezing surface temperatures), or a shallow layer of fog will form.

c. Condensation Nuclei. Condensation nuclei, such as smoke and salt particles, suspended in the air provide a base around which moisture condenses. Although most regions of the earth have sufficient nuclei to permit fog formation, the amount of smoke particles and sulphur compounds in the vicinity of industrial areas is pronounced. In these regions, persistent fog may occur with above average temperature-dew point spreads.

8-3. Fog Dissipation

Fog tends to dissipate when the relative humidity decreases. During this decrease, the water droplets evaporate or ice crystals sublimate and the moisture is no longer visible. Either strong winds or heating processes may cause the decrease in relative humidity.

a. Strong winds cause large eddies in an inversion layer and mix the warm, dry air from aloft with the cool, saturated air at the surface. The mixing widens the temperature-dew point spread, and the fog evaporates near the surface. (Stratus clouds may still exist above the air currents.)

b. Air heated by daytime solar radiation or by the adiabatic process as the air flows downslope increases the air temperature, and the fog evaporates. Therefore, most fogs dissipate shortly after sunrise, and fog is rare on the lee sides of hills and mountains.

8-4. Fog Types and Characteristics

a. Radiation Fog. Radiation fog (fig 8-1) forms after the earth has radiated back to space the heat gained during daylight hours. By early morning the temperature at the surface may drop more than 20° F. Since the dew point temperature (moisture content) of the air normally changes only a few degrees during the night, the temperature-dew point spread will decrease as the air is cooled by contact with the cold surface. If the radiational cooling is sufficient, and other conditions are favorable, radiation fog will form. Radiation fog is most likely when the—

- (1) Sky is clear (maximum radiational cooling).
- (2) Moisture content is high (narrow temperature-dew point spread).
- (3) Wind is light (less than 7 knots).

Note. These conditions are common over land areas in high pressure cells. The resulting fog often occurs in patches of varying density and size.

b. Advection Fog.

(1) The cause of advection fog formation is the movement of warm, moist air over a colder surface. Advection fog (fig 8-2) is common along coastal regions where the temperature of the land surface and the water surface contrasts. The southeastern area of the United States provides ideal conditions

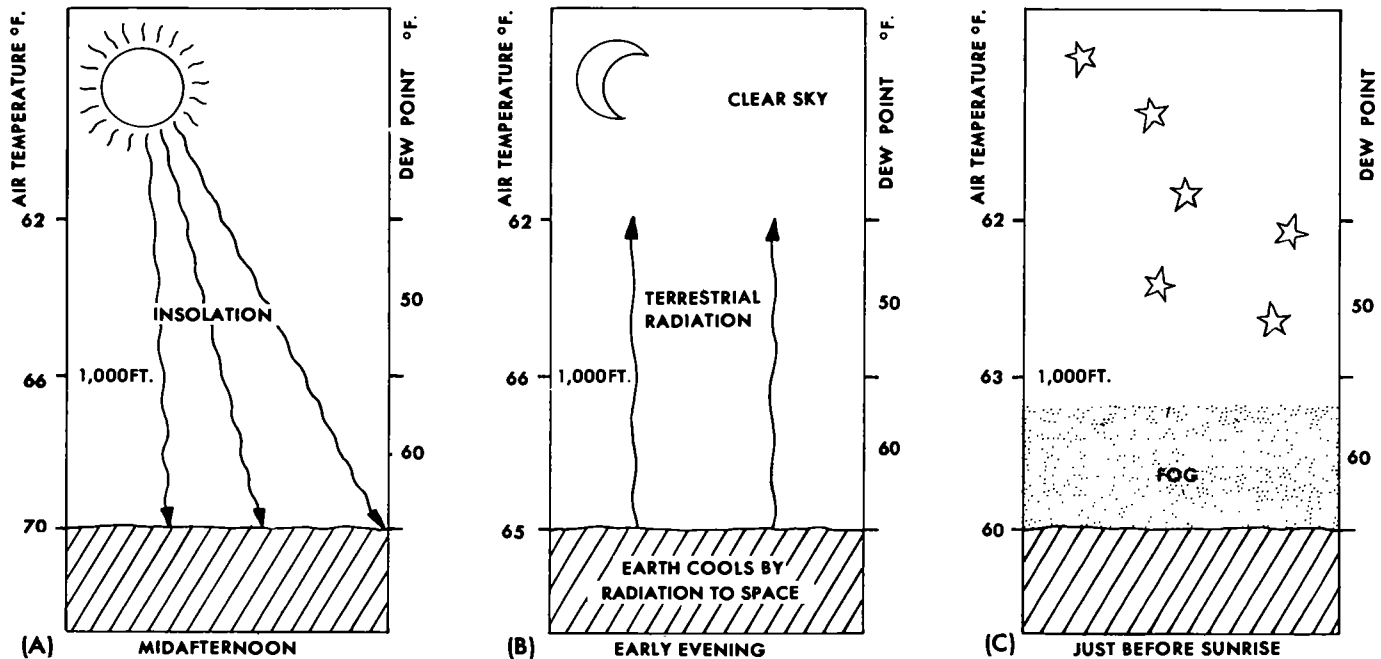


Figure 8-1. Radiation fog.

for advection fog formation during the winter months. If air flows (advection) from the Gulf of Mexico or the Atlantic Ocean over the colder continent, this warm air is cooled by contact with the cold ground. If the temperature of the air is lowered to the dew point temperature, fog will form. Advection fog forming under these conditions may extend over the entire eastern two-thirds of the Nation from the Rockies to Maine. It may persist both day and night until replaced by a drier air mass.

(2) If advection fog forms over water and is carried onshore by the wind, it is often referred to as *sea fog*. Cold ocean currents, such as those off the coast of California, may cool and saturate moist air coming from the warmer areas of the open sea. Sea fog is often very dense both offshore and onshore.

(3) As advection fog moves inland during the winter, the colder land surface often causes sufficient contact cooling to keep the air saturated. The fog may then persist during the day or with a wind speed of 10 to 15 knots.

c. Upslope Fog. Upslope fog forms when moist, stable air flows up a sloping land surface. When the air rises, it cools by expansion (adiabatic cooling) as the atmospheric pressure decreases. When the expansional cooling is sufficient to lower the temperature of the air to the dew point temperature, upslope fog may form. The windspeed (pressure gradient) must be adequate to support continued upslope motion; however, if the wind is too strong, the fog may be lifted from the surface, resulting in an overcast of low stratus clouds. Upslope fog is common on the eastern slope of the Rockies as air flows westward from the Missouri Valley or the Gulf of Mexico.

d. Valley Fog. During the evening hours, cold, dense air will drain from areas of higher elevation into low areas of valleys. As the cool air accumulates in the valleys, the air temperature may decrease to the dew point temperature, causing a dense formation of *valley fog*. While higher elevations may often remain clear throughout the night, the ceiling and visibility become restricted in the valley.

e. Ice Fog. When air near the surface becomes saturated in extremely cold regions, fog will form as ice crystals rather than water droplets. At temperatures of approximately -25°C . and below, water vapor sublimates into ice crystals without passing through a liquid state. The resulting ice crystals are very small and usually persist in an area for many hours as *ice fog*. Atmospheric conditions favoring ice fog formation are common during the winter in north central United States and Canada. On many occasions, however, the air in these cold regions is so free of impurities that sublimation nuclei are insufficient to permit ice fog formations; the air may then become supersaturated. With supersaturated conditions, routine runup of an aircraft engine can supply enough exhaust impurities and moisture to cause sublimation. The resulting ice fog may be serious enough to halt aviation operations at the airfield for hours.

f. Evaporation Fog. Fog formed by the addition of moisture to the air is called *evaporation fog*. Two important types are *frontal fog* and *steam fog*.

(1) **Frontal fog.** Frontal fog is normally associated with slow-moving winter frontal systems (chap 7). Frontal fog forms when liquid precipitation, falling from the maritime tropical air above the frontal surface, evaporates in the polar air below the frontal

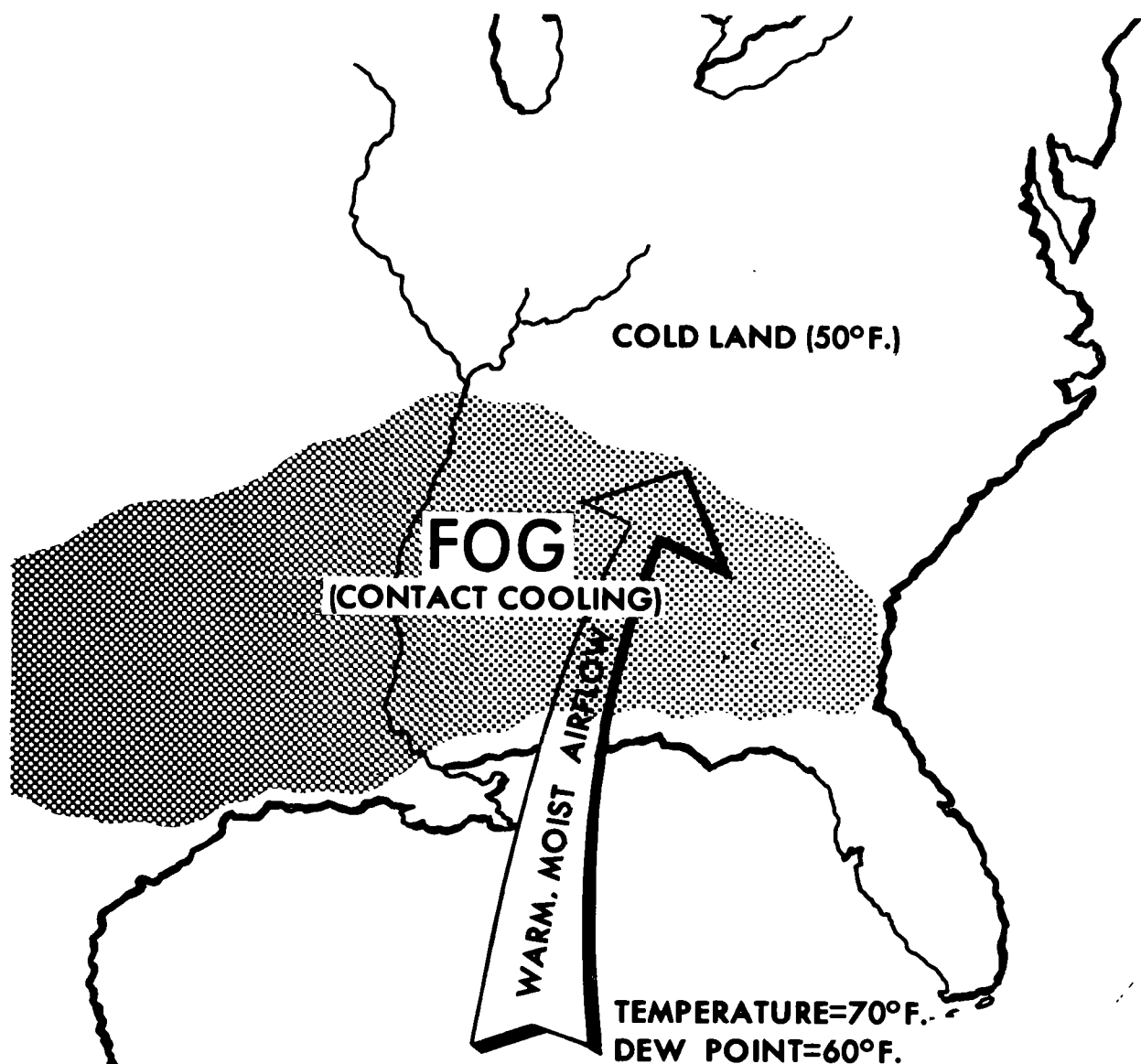


Figure 8-2. Advection fog.

surface. Evaporation from the falling drops may add sufficient water vapor to the cold air to raise the dew point temperature to the temperature of the air. The cold air will then be saturated, and frontal fog will form. Frontal fog is common with active warm fronts during all seasons. It occurs ahead of the surface front in an area approximately 100 miles wide, and is frequently mixed with intermittent rain or drizzle. When fog forms ahead of the warm front, it is called *prefrontal fog*. A similar fog formation may occur in the polar air along a stationary front. Occasionally a slow-moving winter cold front with light wind may generate fog. This fog forms in the polar air behind the surface front and is known as *postfrontal fog*.

(2) *Steam fog*. Steam fog forms when cold, stable air flows over a water surface which is several degrees warmer than the air. The intense evaporation of moisture into the cold air saturates the air and

produces fog. Conditions favorable for steam fog are common over lakes and rivers in the fall and over the ocean in the winter when an offshore wind is blowing.

8-5. Flight Planning

a. An aviator should consider the possibility of fog formation at his destination and at alternates during flight planning, especially when the field is on or near the coast or large bodies of water. If a destination is near the water with an onshore wind, an alternate should be selected inland, preferably behind a hill or ridge. A ridge or range of mountains will act as a barrier and prevent fog from moving inland.

b. A check of the facilities in the weather station can help the aviator anticipate areas and times of fog formation. The teletype sequence reports (chap 11) show the tendency of the temperature-dew point spread; this tendency may be projected to the time

when the spread will become critical. Terminal forecasts indicate the expected ceiling and visibility at the forecast time of fog formation and/or dissipation. Surface weather maps and sequence reports, used together, indicate frontal precipitation areas where fog is likely to form. These two facilities also indicate the direction and velocity of the wind in relation to topography. This relationship is beneficial in predicting areas of advection or upslope fog formation.

c. Fog is sometimes difficult to forecast and may be an unexpected landing hazard. If an aviator, upon reaching a destination, finds that fog has formed and the ceiling and visibility are below minimums, he should immediately proceed to the alternate field.

d. The aviator should consult the forecaster about all probable fog areas since slight changes in temperature, moisture, and wind direction or speed can cause fog to form or to dissipate.

CHAPTER 9

ICING

9-1. General

The formation of ice on lift producing airfoils (airplane wings, propellers, helicopter rotors, and control surfaces) will disrupt the smooth flow of air over the airfoils. This will result in decreased lift, increased drag, increased stall speed of fixed wing aircraft, and decreased retreating blade stall speed of rotary wing aircraft. Under ordinary circumstances, the danger of added weight is not too great. If, however, too much lift and thrust are lost simultaneously, weight also becomes an important factor, especially when the aircraft is critically loaded. The formation of ice on some structural parts of an aircraft may cause vibration and place added stress on those parts. *For example*, vibration caused by a very small amount of ice unevenly distributed on a delicately balanced rotor or propeller can place dangerous stress on the system, transmission, and engine mounts.

9-2. Factors Necessary for Structural Ice Formation

Factors necessary to produce structural icing on aircraft in flight are outside air temperature (OAT) at or below freezing and presence of visible liquid moisture in the form of clouds or precipitation.

a. Free Air Temperature. When saturated air flows over a stationary object, ice may form on the object when the free air temperature is as high as 4° C. The surface temperature of the object is cooled by evaporation and by pressure changes in the moving air current. When an object is moving through saturated air, the surface of the object is heated by friction and the impact of waterdrops. On an aircraft in flight, these cooling and heating effects tend to balance; therefore, structural ice may form when the outside air temperature is at or below 0°. The most severe icing occurs with temperatures between 0° and -10° C.; however, under some circumstances, dangerous icing conditions may be encountered with temperatures below -10° C. The accuracy of the aircraft OAT gauge may also be significant in determining potential icing areas. Even when a record is kept of the instrument error or the instrument has been calibrated correctly, other influences (para 2-7) may cause the temperature reading to be at least 3° C. warmer or colder than the true outside air temperature.

b. Visible Liquid Moisture.

(1) Clouds are the most common form of visible liquid moisture; however, not all clouds with temperatures below freezing produce serious ice formation. Although serious icing is rare in temperatures below -20° C., the aviator must recognize that icing is *possible* in any cloud where the temperature is below 0° C.

(2) Freezing rain, which occurs in the cold air below a frontal inversion, is another form of visible liquid moisture that causes icing. Raindrops falling into a layer of cold air become supercooled when the air temperature is freezing or below. When these subfreezing liquid waterdrops strike an object (such as an aircraft), they turn to ice on the object. Freezing rain is probably the most dangerous icing condition; it can build hazardous amounts of ice in a few minutes. This ice is extremely difficult to break loose.

9-3. Types of Aircraft Structural Ice

Aircraft structural icing may be *clear*, *rime*, a *combination of clear and rime (glime)*, or *frost*. The type of ice that forms on a moving structure normally depends on four factors—(1) the outside air temperature, (2) the surface temperature of the structure, (3) the surface characteristics of the structure (configuration, roughness, etc.), and (4) the size of the waterdrops.

a. Clear Ice (Glaze). Clear ice, also called *glaze*, is the most serious form of structural ice. It is normally caused by the large supercooled waterdrops found in cumuliform clouds where the temperature is between 0° C. and -10° C. or in areas of freezing rain associated with warm frontal systems (fig 9-1). A typical clear ice formation is transparent or translucent, with a glassy smooth or rippled surface (fig 9-2). Transparent glaze resembles ordinary ice and is identical to the glaze which forms on trees and other objects as freezing rain strikes the earth. When mixed with snow, sleet, or small hail, the glaze may be rough, irregular, and whitish. Large supercooled waterdrops tend to spread out on a surface before they freeze. The resulting glaze adheres firmly to the surface and is difficult to remove. Glaze formation on the leading edges of rotors, propellers, wings, and antennas often takes a blunt-nose shape tapering toward the rear. When deposited as a result of the

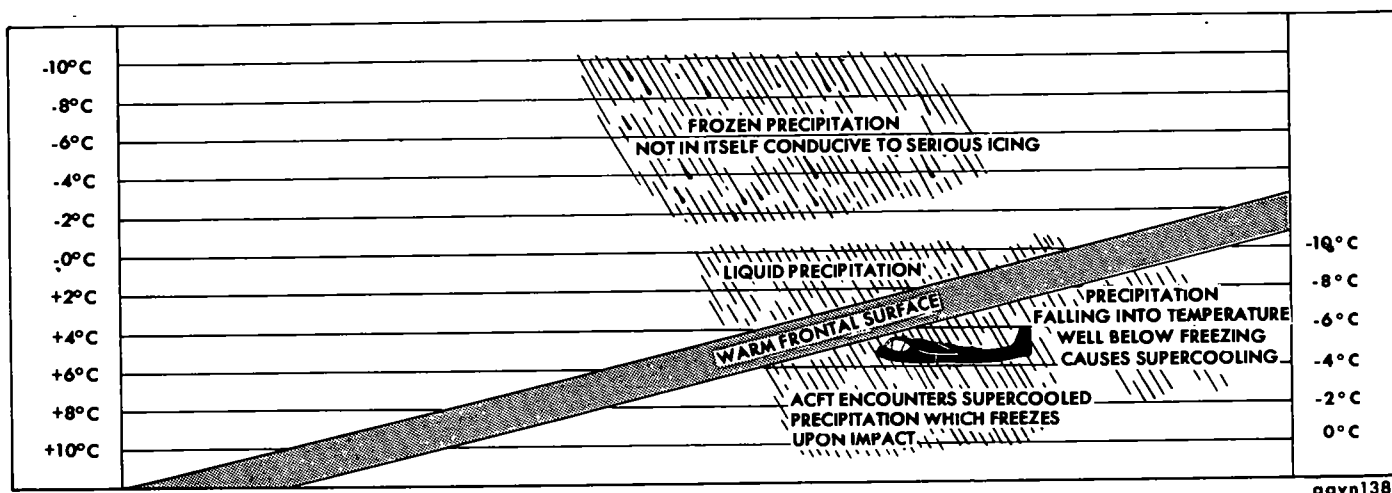


Figure 9-1. Typical freezing rain situation.



Figure 9-2. Formation of clear (glaze) and rime ice on aircraft armament.

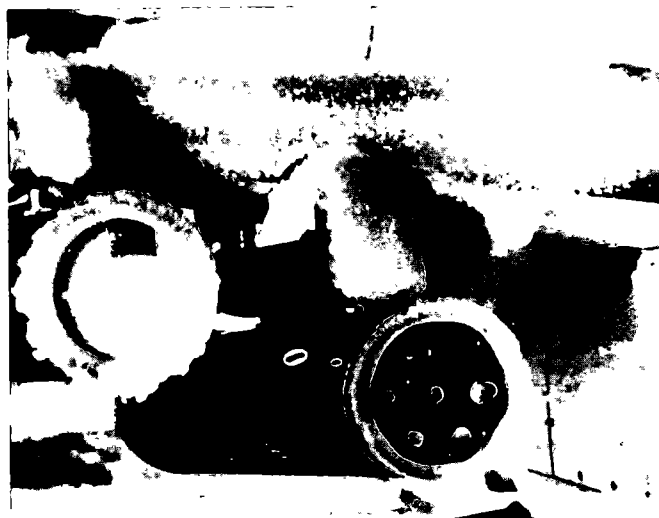


Figure 9-3. Rime ice formation on aircraft wing stores.

freezing of supercooled raindrops or very large clouddrops, the glaze deposit may become especially blunt-nosed with heavy protuberances which build outward perpendicular to the leading edge of an airfoil.

b. Rime Ice. Rime ice is normally encountered in regions of small supercooled water droplets, either in stratiform clouds where the temperature ranges from 0° C to -20° C. or in cumuliform clouds with temperatures from -10° C. to -20° C. It is a white or milky, opaque, granular deposit of ice which accumulates on the leading edges of airfoils and other structural parts of an aircraft (fig 9-3 and 9-4). Rime ice has a granulated, crystalline or splintery structure with a rough surface. The interior is composed of very tiny, opaque ice pellets or grains, which may be intermixed with a frost formation of feathery crystalline structure. Some airspaces are present because the



Figure 9-4. Rime ice on aircraft armament.

small water droplets do not spread out before they freeze. Rime ice is less compact than glaze and does not adhere tenaciously to exposed objects. Rime ice often accumulates on the leading edges of exposed parts and projects forward, sharp-nosed, into the air stream. Except for a limited region near the center of the leading edge, rime ice generally shows little or no tendency to adhere to the contour of an airfoil. When supercooled water droplets strike surface projections of the aircraft, the ice deposit acquires the form of a bulge which may cling rather firmly to the projecting part of the aircraft structure. The protruding bulges may then grow into rough, irregular formations.

c. Frost.

(1) Frost is composed of ice crystals and is formed by sublimation when water vapor contacts a cold surface. On the ground, it may form during a clear night on subfreezing surfaces. (The temperature of the air over the surface may be above freezing.) Frost may also form in flight during descent into warmer moist air or when the aircraft passes from a subfreezing air mass into a slightly warmer moist air mass at the same altitude.

(2) Aviators tend to underestimate the flight

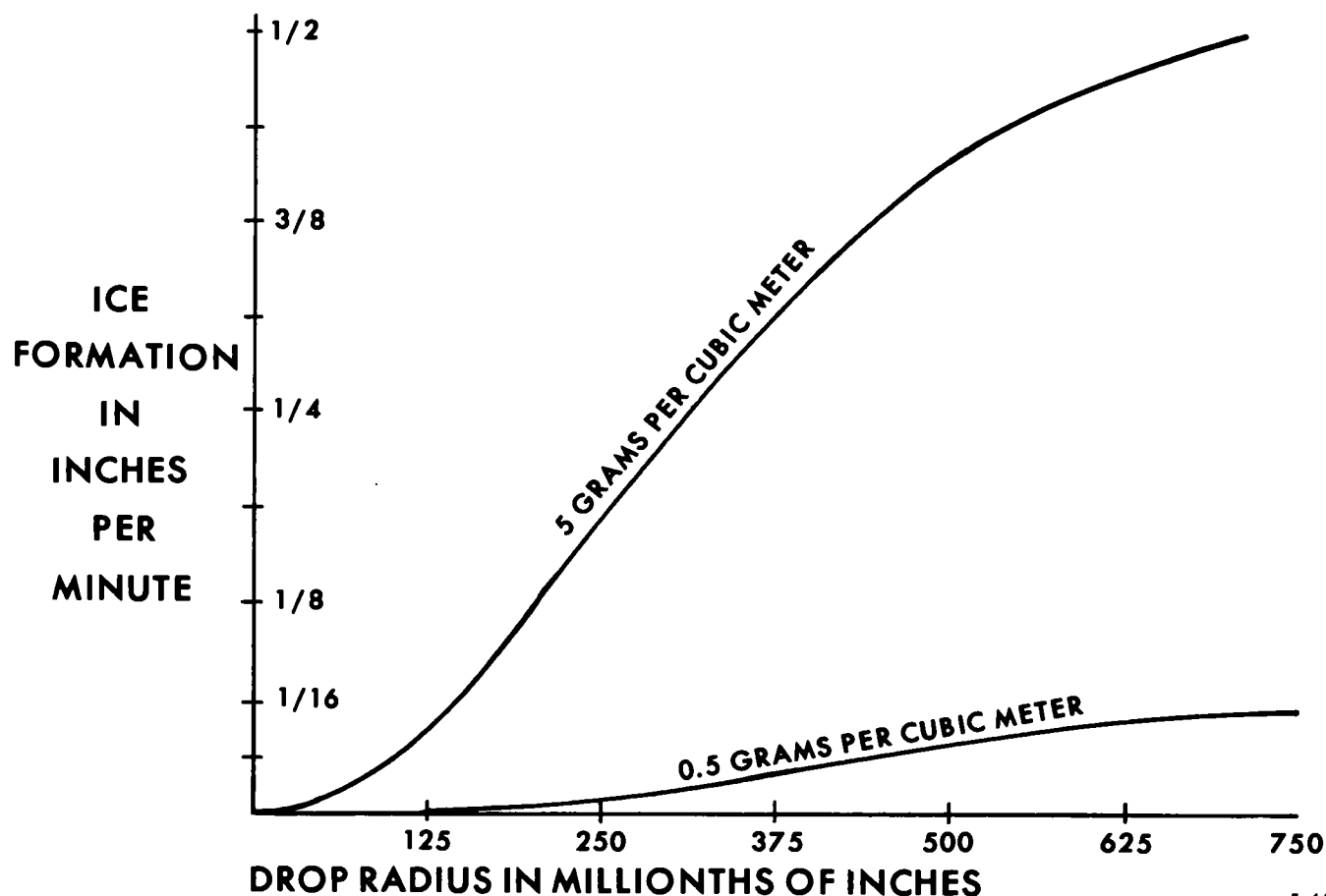
hazards of frost formations. Frost increases drag and is particularly hazardous at low airspeeds during takeoff and landing. If frost is left on the aircraft during takeoff, the small ice crystals act as sublimation nuclei and may grow to serious proportions during the takeoff and climbout. Frost on the windshield may cause restriction to, or total loss of, visibility.

9-4. Factors Influencing the Rate of Ice Formation

a. Amount of Liquid Water. Ice formation is more rapid in dense than in diffuse clouds. The rate of ice formation increases as the amount of supercooled liquid water in air increases.

b. Drop Size. Water droplets in the air tend to move with the deflected airstream—the smaller the water-drops, the greater their tendency to follow the airstream; the larger the drops, the more they resist the deflecting influence (fig 9-5). Therefore, the large drops (small deflection) collect on an airfoil more easily than the small drops (large deflection).

c. Airspeed. The rate of ice formation is increased by an increase in airspeed. At very high speeds, such as those attained by jet aircraft, the situation is



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Figure 9-5. Rates of ice formation.



Figure 9-6. Windshield ice.

reversed because skin friction provides enough heat to melt structural ice. At true airspeeds above 575 knots, structural ice is seldom a problem. The airspeed at which frictional heating will prevent ice formation varies with the aircraft (type, configuration, surface characteristics, etc.) and the outside air temperature.

d. Smoothness. The smoothness of the aircraft and airfoil surface also affects the rate of icing. Initial accumulation creates an aerodynamically unclean configuration and presents a larger surface area to collect the freezing droplets.

9-5. Effects of Icing on Aircraft

Aircraft icing can have a serious adverse effect on the performance of an aircraft in at least four ways. First, ice can cause a mechanical or visual obstruction; second, ice can modify the profile of part of the aircraft, reducing its aerodynamic efficiency; third, ice can alter the frequency of some parts of the aircraft so that serious vibration may be induced. Lastly,

ice that has formed can break off and cause serious mechanical damage or engine flame out or produce an asymmetric condition on a rotating mechanism (such as a helicopter rotor) which will give rise to serious vibration.

a. Pitot Tube. Ice in a pitot tube will reduce the size of the opening and change the flow of air in and around it. As a result, the flight instruments which are part of the pitot static system (i.e., airspeed indicator, vertical speed indicator, and altimeter) will become unreliable.

b. Windshield. The formation of ice or frost on windshields of aircraft is most hazardous during takeoffs and landings. Insignificant frost particles on the windshield prior to takeoff may act as sublimation nuclei during takeoff and reduce visibility to near zero before the aircraft leaves the runway. Ice accumulation on the windshield during letdown may prevent visual contact with the runway (fig 9-6 and 9-7).



Figure 9-7. Frost and ice on windshield.

c. Fuel Vent. Heavy ice buildup on aircraft surfaces may block fuel vents. As fuel is used, a blocked vent will prevent air replacing fuel being withdrawn from the tank, causing a partial vacuum in the tank, which may prevent the flow of fuel to the engine or cause the fuel tank to collapse.

9-6. Icing on Rotary Wing Aircraft

Future generation Army helicopters will be capable of performing missions under all-weather conditions. A capability for helicopter flight in icing conditions will allow a vast majority of airmobile operations to be performed under adverse weather conditions even without IFR terrain avoidance and target acquisition capability. The most pressing need is to enable the helicopter to arrive safely and functional at its destination. Once there, mission completion is dependent upon local conditions. Without a capability for flight in icing conditions airmobile operations will have to be cancelled or delayed until en route weather conditions permit. In Europe, weather statistics indicate that during winter months, airmobile operations cannot be employed approximately 35% of the time because of icing conditions. From a strategic standpoint, this limitation is intolerable.

a. Helicopter Icing Levels. Studies by military and civilian research agencies reveal that generally, when the windshield is obscured, the severity level is reported as moderate or severe. If the windshield wiper blades, door handles, and skids begin to accumulate ice, the reports generally range from trace to moderate. In either of these cases, the main rotor blade may not be accumulating ice, but if the pilot cannot see to land or has to make a side-slip approach to gain visibility, he considers it a serious or severe condition. Also generally, if torque increases or vibrations are observed by the pilot, he usually reports this as a

moderate or severe icing condition. Although the situation may be critical, this does not imply that the icing severity level falls into the severe category.

b. Rotor Systems. Ice formation on the helicopter main rotor system or antitorque rotor system may produce critical vibrations and loss of efficiency or control. Although the slower forward speed of the helicopter reduces ice accumulation on the fuselage, the rotational speed of main and tail rotor blades produces a rapid growth rate on these surfaces.

(1) *Main rotor head assembly.* The rotating parts of the flight controls systems, although subject to ice buildup, do not normally suffer any adverse effects since they are in continuous cyclic motion. Movement of other parts of the control system subject only to random linear motion may be restricted due to the accumulation of ice (fig 9-8).

(2) *Main rotor blades.* An increase in the indicated torque accompanies ice accumulation on the main rotor and is a useful indication of ice buildup. With an excess ice accumulation on the inboard portions of the main rotor (which is indicated to the pilot by an increase in torque pressure) it may not be possible to maintain an autorotational rotor speed above the lower limit. The resulting low rotor speed provides insufficient rotor kinetic energy to ensure a safe autorotational landing. Flights should not be continued when it is determined that ice accumulation on the main rotor degrades the autorotational capability.

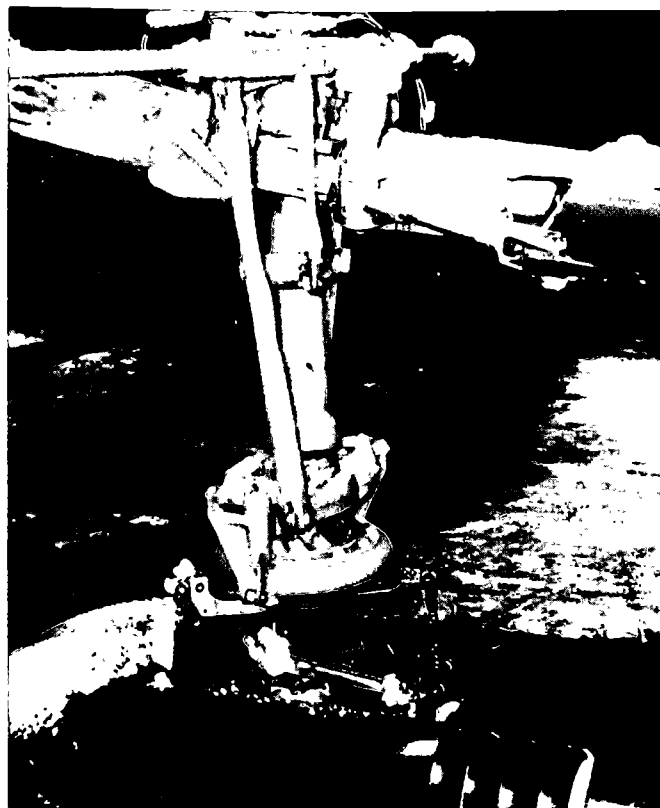


Figure 9-8. Main rotor head icing.



Figure 9-9. Main rotor icing.



Figure 9-10. Irregular rotor blade icing pattern.



Figure 9-11. Cross-section of rotor blade icing.

ity. Deliberate control inputs may be induced to cause ice to shed from the blades. However, this procedure should not be used because ice may shed asymmetrically, resulting in severe rotor vibrations. A critical icing hazard can form rapidly on the center two-thirds of the main rotor blades (fig 9-9 through 9-11).

(3) *Tail rotor.* Ice accumulation on either the antitorque rotor head assembly or blades produces the same hazards as those associated with the main rotor. The centrifugal force of rotation and the blade angle of incidence relative to the clouds help to reduce ice buildup on the tail rotor blades, but the shedding of ice from the blades may damage the fuselage or the main rotor.

c. Air Intake Screens. Ice accumulation on the engine and transmission air intake screens is more rapid than accumulation on the rotor systems. This results in inadequate cooling of the engine and transmission. Freezing water passing through the screens

also coats control cables and may produce limited throttle movement and similar control problems (fig 9-12 and 9-13).

d. Airframe. Ice deposited on the airframe is unlikely to present any problem from weight growth, as it is mainly limited to those parts which present a relatively small projected area to the airstream. The main problems arise from the buildup of ice on external struts, pipes and other projections of small sections which have a high catchment rate. In these cases the ice tends to build in a form which will eventually be shed by aerodynamic forces when it extends beyond a certain amount or the shedding may be initiated if the aircraft, having encountered icing conditions, then descends through warmer air.

e. Antennas. Buildup and shedding of ice on antennas can cause severe oscillations and may even affect communications. Accumulation and shedding of ice on the FM whip antenna can cause large amplitude oscillations causing the antenna to strike the tail rotor.

Note. Tests are currently being conducted by military agencies and civilian industrial firms to better determine the effects of icing on rotary wing aircraft during powered and autorotative flight.

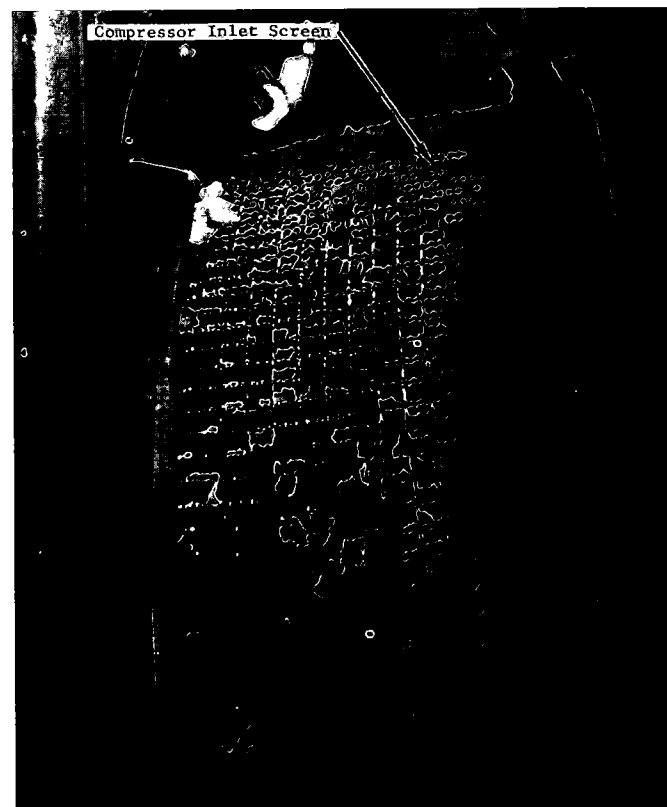


Figure 9-12. Engine air intake screen icing.



Figure 9-13. Engine air intake screen icing.

9-7. Icing on Fixed Wing Aircraft

a. Wing and Tail Surfaces. Structural ice on wing and tail surfaces, disrupting the flow of air around the airfoil, causes a loss of lift and an increase in drag, and results in a higher-than-normal stall speed (fig 9-14).

b. Propeller. The accumulation of structural ice on

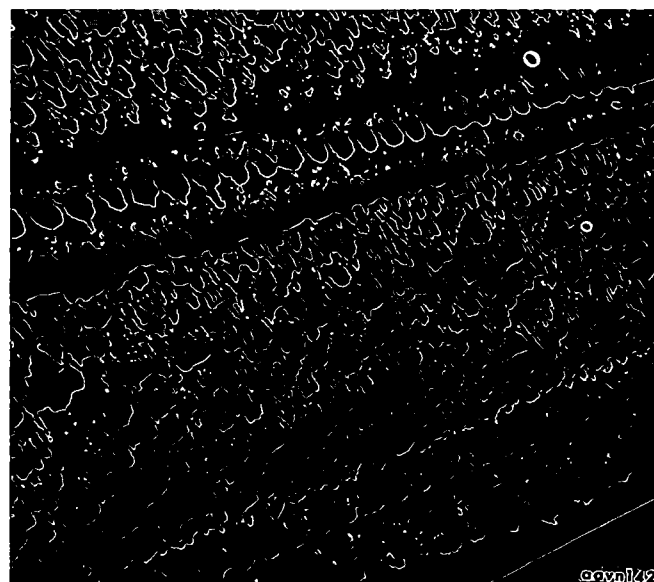


Figure 9-14. Undersurface of wing aerodynamically unclean because of ice formation.

propeller hubs and blades causes an unbalance which may produce severe vibration. Ice on the propeller blades spoils the aerodynamic properties of the airfoil and results in a loss of thrust. Increased throttle or power settings may then fail to produce sufficient thrust to maintain flying speed.

c. Control Surfaces. Icing on aircraft control surfaces (ailerons, elevators, rudder, etc.) disrupts their aerodynamic characteristics and/or restricts their movement. A restriction to movement occurs when ice accumulates around protruding hinges.

d. Induction System Icing. Induction system ice (fig 9-15) may form in such places as the air scoop,

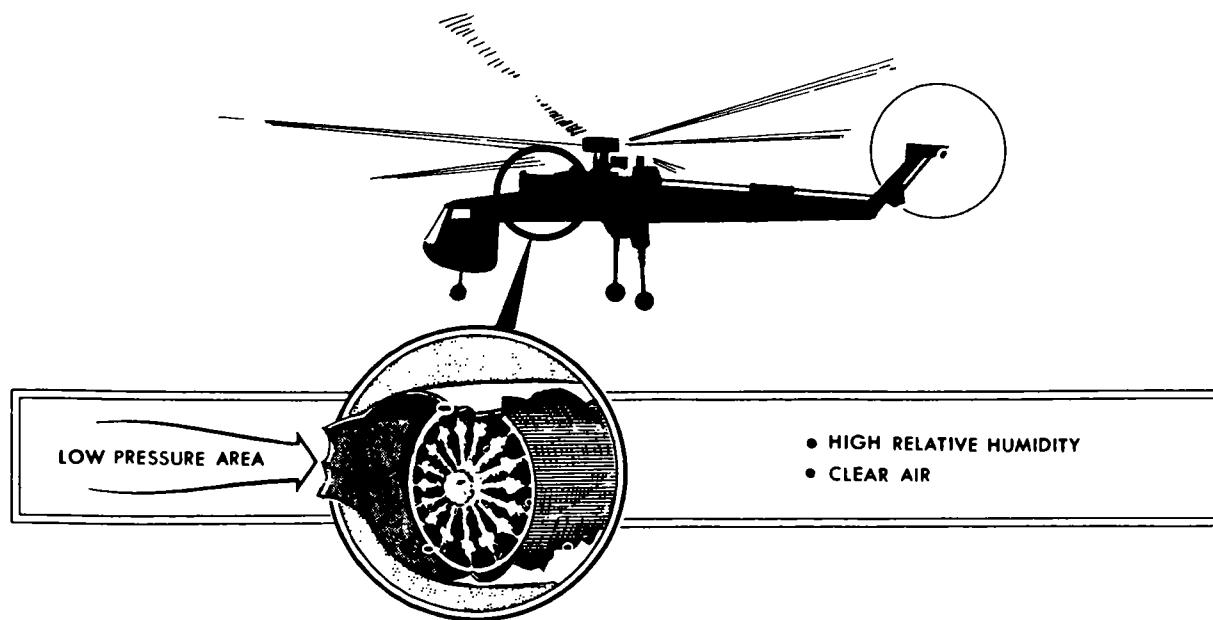


Figure 9-15. Induction system icing.

screens, particle separators, and in curves of the induction system. Some of the best indicators of induction system icing is a loss in power, increased exhaust gas temperatures (EGT), and increased engine oil and transmission oil temperatures.

9-8. Icing in Turbojet Engines

a. Turbojet engines with axial flow compressors are seriously affected by the same atmospheric conditions which cause wing icing. Ice over the inlet guide vanes restricts airflow, thereby producing less thrust, excessive turbine temperatures, and probable turbine failure. Severity of the internal icing conditions is indicated by the turbine tailpipe temperature. The rate of ice formation is in proportion to the intensity of the icing condition (para 9-13) and the flow of air through the engine (rpm).

b. Although jet engine icing occurs under the same conditions as wing icing, the rate of formation is different. The amount of engine icing depends upon the concentration of water and is almost independent of the size of the waterdrops. For a given concentration of water in the atmosphere and for a given airspeed and engine rpm, the engine icing rate will be constant, but wing icing formation will be lighter with small drops (para 9-4b). Objects which protrude into the airstream with a small radius of curvature (tail surfaces, antennas, and pitot tube braces) provide the most reliable visual indication of the rate of engine icing.

c. A low airspeed will reduce the rate of ice formation both in the engine and on the structural surfaces. However, the aviator should maintain a close watch on turbine tailpipe temperature whenever internal icing is suspected.

9-9. Weather Areas Conducive to Icing

a. *Frontal Inversions.* When warm air is forced to rise over a colder air mass, a frontal inversion is present (fig 9-1). Below the inversion, structural icing areas are common in winter.

(1) Warm moist air displaced by the frontal surface cools by expansion and produces thick clouds and precipitation. The raindrops falling from the warmer air through the wedge of cold air may be cooled below 0° C., but the drops will remain liquid if their round shape is not disturbed. When the supercooled waterdrops strike an aircraft, their shape changes and they freeze on the aircraft. The large precipitation drops (freezing rain or freezing drizzle) produce a rapid formation of glaze in a short period of time. Often the freezing precipitation is mixed with ice pellets (frozen raindrops) or snow (ice crystals) as it falls through cold air to the surface.

(2) An aviator should escape from an area of freezing precipitation by climbing to the warmer air

above the frontal inversion. Prior to flight into the frontal area, the altitude of the inversion can be obtained from the Skew T, Log p Diagram, from upper air charts, or from teletype weather reports. The inversion layer is indicated by a temperature increase and a distinct wind shift through a relatively narrow atmospheric layer (500 to 1,000 feet). Descending to avoid the freezing precipitation may not resolve the icing problem because freezing rain or drizzle may extend to the surface, covering power lines, trees, and runways with a solid coating of ice. Reversing course in flight will prolong the flying time in the serious icing area and increase the ice accumulation.

Warning: An aviator should not descend to avoid freezing precipitation unless he knows the temperature at his planned altitude near the surface is above freezing.

b. *Suspended Supercooled Water Droplets (Clouds).*

(1) *Stratiform clouds.* Stratiform clouds indicate stable air in which either minute water droplets and/or ice crystals are suspended. The ice crystals present no icing problem since they do not stick to the aircraft upon impact. The small supercooled water droplets, however, will freeze into rime ice upon contact with the aircraft. Glaze may form in the rain zones of stratiform clouds, and often a combination of rime ice and glaze will form in some areas of the clouds. Where icing zones occur in stratiform clouds, aircraft should either be flown *under* the icing zones where the temperature is above freezing or *above* the zones where only ice crystals are present.

(2) *Cumuliform clouds.* Cumuliform clouds indicate unstable air in which strong vertical currents can support large supercooled liquid drops. Upon impact with aircraft, these large drops spread out before turning to ice. The resulting glaze adheres tenaciously to the aircraft. Since large waterdrops accumulate rapidly in areas of high liquid concentration, icing quickly becomes a serious hazard in icing zones of cumuliform clouds. Figure 9-5 shows the relation between the rate of ice formation and the drop size when the cloud contains a large amount of liquid water (5 grams per cubic meter) as contrasted to a smaller amount (0.5 grams per cubic meter).

c. *Mountainous Terrain.* The lifting of conditionally unstable moist air over mountain ranges during the winter is one of the major ice-producing processes in the United States. When *MT* air moves over the Appalachian Mountains, it is often cooled to freezing temperatures. An icing hazard exists for all flights through this air. Similarly, *MP* air approaching the west coast of the United States contains considerable moisture in its lower levels. As the air is forced aloft by the successive mountain ranges encountered in its

eastward movement, severe icing zones develop. Figure 9-16 shows typical icing regions along parallel ridges. The most severe icing will take place above the crests of the mountains and to the windward side of the ridges. Usually the icing zone extends about 4,000 feet above the tops of the mountains. In unstable air, the icing may extend to higher altitudes. The movement of a front across a mountain combines two weather areas in which serious icing may occur. A study of icing in the Western United States has shown that almost all the icing conditions occurred where the air was blowing over a mountain slope, or up a frontal surface or a combination of both.

9-10. Polar Icing Reports

a. A summary of 14,843 pilot reports compiled during World War II indicates the following icing facts concerning flight operations north of 60° north latitude. (The temperatures used below are free air temperatures as reported by standard aircraft instruments. The reported flight altitudes ranged from 7,000 feet to 12,000 feet, and the reports were for the Alaskan Region.).

(1) Only 1,409 of the total 14,843 pilot reports mentioned icing of any type.

(2) The month of maximum occurrence of severe icing was February.

(3) The month of maximum *icing reports* of all types was February.

(4) The month of least occurrence of icing was September.

(5) Of all types of icing reported, rime ice, especially moderate rime ice, was the predominate type found at low temperatures in all seasons.

(6) There have been isolated reports of icing at extremely cold temperatures.

(7) Severe ice in summer was reported at temperatures from 0° C. to -8° C.

(8) Severe ice in the winter was normally reported at temperatures from 2° C. to -8° C.

(9) When observations of icing conditions were possible, icing appeared least at a temperature of -11° C.

b. *Light icing* was classified as a formation of a mere trace to 0.2 inch in 5 minutes; *moderate icing*, as a buildup of from 0.2 to 1.5 inches of ice in 5 minutes. *Severe icing* was reported where the rate of formation was greater than 1.5 inches in 5 minutes.

9-11. Condensed Icing Facts (Structural Ice)

a. General.

(1) Icing conditions should be expected in cloud layers where the air temperature ranges from 0° C. to -20° C.

(2) Icing hazards above the clouds are not great.

(3) Severe icing should be expected in rain or drizzle below a cloud where the air temperature is less than 0° C.

(4) Ice crystals will not adhere to an aircraft.

(5) Icing is severe in winter frontal zones.

(6) Icing is severe in upslope moist air movement over mountains during the winter.

(7) Most structural ice formations are a combination of rime and clear ice.

b. Clear Ice.

(1) Clear ice is predominant in cumuliform clouds where temperatures range from 0° C. to -10° C.

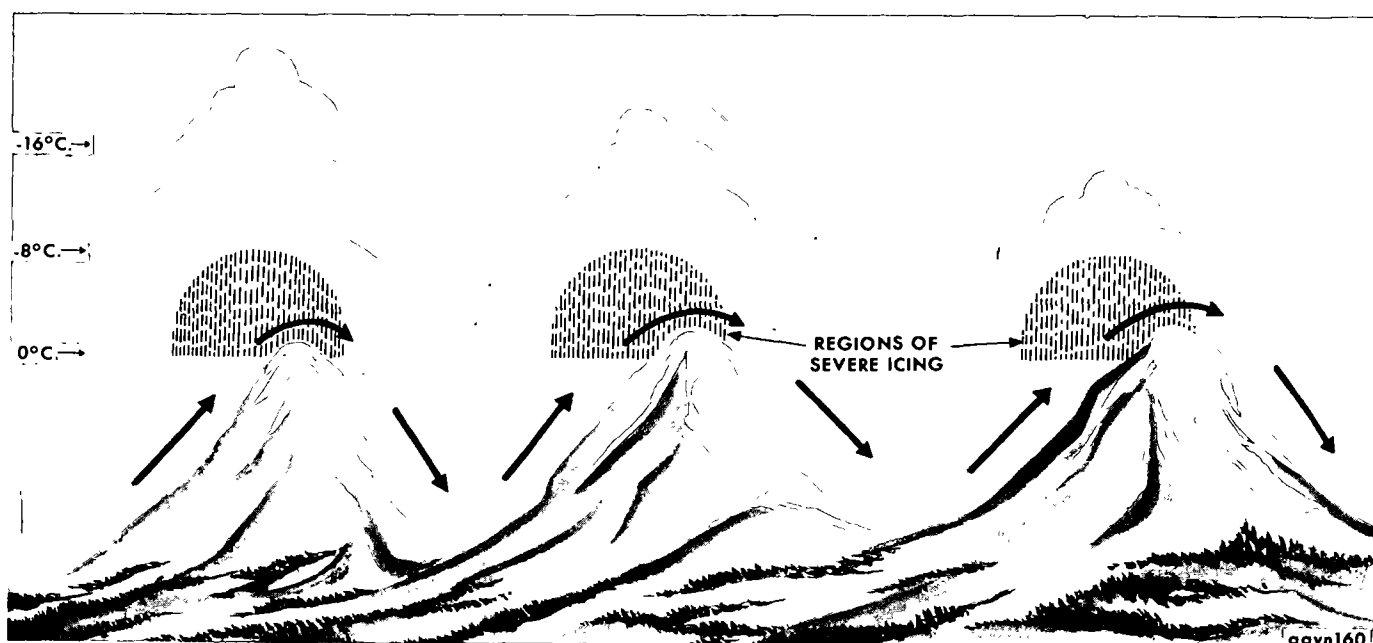


Figure 9-16. Icing over mountains.

(2) Clear ice is found in freezing precipitation below clouds.

(3) Clear ice is more hazardous than rime ice.

c. Rime Ice.

(1) Rime ice is predominant in stratiform clouds where temperatures range from 0° C. to -20° C.

(2) Rime ice is common in cumuliform clouds where temperatures range from -10° C. to -20° C. and the supercooled droplets are less numerous and smaller in size.

9-12. Checklist for Cold Weather Operations

Following is a winter checklist that will help reduce hazards of cold weather flying:

a. Check weather carefully; ask the aviator who just came through.

b. Check NOTAMs.

c. Remove as much frost and snow as possible before takeoff.

d. Check controls for restrictions of movement.

e. Hover or taxi slowly. Use brakes with caution.

f. After runup in fog or rain, check for ice in rotor or propeller wash areas.

g. Wear sunglasses if glare is bad.

h. In fixed wing aircraft avoid taking off in slush or wet snow and avoid snowbanks, if possible. Rotary wing aircraft should maintain a high hover over such surfaces to reduce blow-up onto the aircraft.

i. Use pitot heater when flying in rain, snow, clouds, or known icing zones.

j. When flying in freezing rain conditions, climb into the clouds where the temperatures will be above freezing (unless the temperature at a lower altitude is *known* to be high enough to prevent ice).

k. Report all in-flight weather hazards.

l. If icing can't be avoided, choose the altitude of least icing. (Glaze ice is common in cumulus clouds; rime ice is common in stratiform clouds.)

m. Watch airspeed. Airfoil stalling speed increases with the formation of ice.

n. Avoid making steep turns if the aircraft is heavily coated with ice.

o. Before takeoff, insure that anti-icing and deicing equipment is in operating condition.

p. On aircraft with reciprocating engines use carburetor preheat to prevent ice formation; do not wait until an icing condition exists. Watch the carburetor air temperature, especially between -5° C. and +10° C. Use full carburetor heat to clear it of ice. Always maintain carburetor heat whenever carburetor icing is likely.

q. On fixed wing aircraft, check wing deicers; use them properly. Do not land with deicers on since they act as airflow spoilers. Fly in with power. Before starting a landing approach, slowly move throttle

back and forth to make sure the carburetor butterfly valve is free of ice.

Note. When ice forms on the aircraft, more fuel will be required to reach a destination. Increased drag and ice-preventive measures take workpower away from the aircraft and reduce its cruise range. Therefore, if icing conditions are anticipated, a more conservative cruise control also must be anticipated.

9-13. Icing Intensity

The aviator is responsible for reporting the intensity of icing encountered in flight, either upon completion of the flight or as a pilot report (PIREP) (chap 17) during the flight. If the flight is to be made through known or forecast moderate icing, the aircraft must be equipped with adequate deicing/anti-icing equipment. Army aircraft will not be flown into known or forecast severe icing conditions (AR 95-1). The standard criteria for judging the intensity of icing is shown in table 9-1.

Table 9-1. Airframe Icing Reporting Table

Intensity	Ice accumulation
Trace	Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though deicing equipment is not used, unless encountered for an extended period of time (over one hour).
Light	The rate of accumulation may create a problem if flight is prolonged in this environment (over one hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.
Moderate	The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.
Severe	The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

9-14. Deicing and Anti-icing Methods

Deicing and anti-icing methods include the following:

a. Mechanical Boots. On fixed wing aircraft the leading edges of wing and tail surfaces may be equipped with rubber skins or boots that fit the contour of the airfoil. During icing situations, compressed air is cycled through ducts in the rubber boots, causing the boots to swell and change shape. The stress produced by the pulsating boots causes the ice to crack so that the airstream can then peel the ice fragments from the boots.

b. Anti-icing Fluids. Anti-icing fluids are used on rotating surfaces, such as propellers and rotor blades, where the centrifugal force produced by the rotating surface spreads the fluid evenly over the entire surface. Such fluids are effective anti-icing agents because the fluid helps prevent ice from adhering to the coated surface, and the ever-present centrifugal force throws the ice from the surface. Anti-icing fluids will not remove ice which has already formed.

c. Heat. The application of heat to a surface being iced is another method of removing structural ice. Since the leading edges of wings and the tail surfaces are vulnerable to the most serious icing, these areas may be heated by electrical means or by hot air which is piped from the manifold or bleed air of the engine. The process of supplying hot air gave rise to the name "hot wing" aircraft. However, practical considerations of weight, heat exchange characteristics, tem-

perature effects on the structure of the aircraft, and electrical insulation limit the use of thermal deicing equipment.

9-15. Forecasting

The primary cause of icing encounters, which exceed the capability of aircraft, is the accuracy of the forecast. Approximately one-fourth of the icing encounters reported by pilots were during VFR flights. In most of these reports, freezing levels were forecast, but icing was not. On many occasions, icing conditions can be forecast for specific altitudes. The IFR flight plan is assigned a presumably safe altitude free of icing conditions; however, icing may be encountered at the assigned altitude. Data indicates that the majority of all icing encounters occur during cruise flight at altitudes between 1500 and 6000 feet.



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CHAPTER 10

1. THUNDERSTORMS

THIS CHAPTER DOES NOT ADVOCATE FLYING INTO THUNDERSTORMS. THE INFORMATION HEREIN PROVIDES A GENERAL KNOWLEDGE CONCERNING THIS WEATHER PHENOMENA. FLIGHTS SHOULD BE PLANNED TO PRECLUDE INADVERTENT PENETRATION. BEFORE DELIBERATE PENETRATION IS DEEMED NECESSARY, AN INDEPTH EVALUATION OF THE MISSION SHOULD BE ADDRESSED. BASED ON EXPERIENCE AND LIMITED RESEARCH, FLIGHT THROUGH THUNDERSTORMS AND MISSION ACCOMPLISHMENT ARE NOT COMPATIBLE



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CHAPTER 10 THUNDERSTORMS

10-1. General

Thunderstorms contain many of the most severe atmospheric hazards to flight. They are almost always accompanied by strong gusts of wind and severe turbulence, heavy rain showers, lightning, and mixed icing. During thunderstorms, hail is not uncommon, and tornadoes are possible.

a. Because an average of 44,000 thunderstorms occur daily over the surface of the earth, it may be necessary for the Army aviator to fly through a thunderstorm or a thunderstorm area to complete a mission. He must be cognizant of the hazards and flight problems presented by thunderstorms to be able to plan and conduct a flight through an area of turbulence and associated phenomena.

b. When thunderstorms (fig 10-1) are in the flight area, it is sometimes possible to fly around them. The aviator should remain on visual flight rules (VFR) through any known or suspected thunderstorm area,

since cumulonimbus clouds are often concealed by surrounding cloud layers. This practice eliminates the possibility of unintentional thunderstorm penetration.

c. All thunderstorms are similar in physical make-up, but for purposes of identification they are divided into two general groups—*frontal* and *air mass*. This division gives the aviator an indication of the method by which the storms are formed and the distribution of the clouds over the area. The specific nomenclature of these thunderstorms depends upon the manner in which the lifting action occurs as explained in paragraphs 10-3 and 10-4 below.

10-2. Factors Necessary for Thunderstorm Formation

The minimum factors essential to the formation of a thunderstorm are conditionally unstable air with

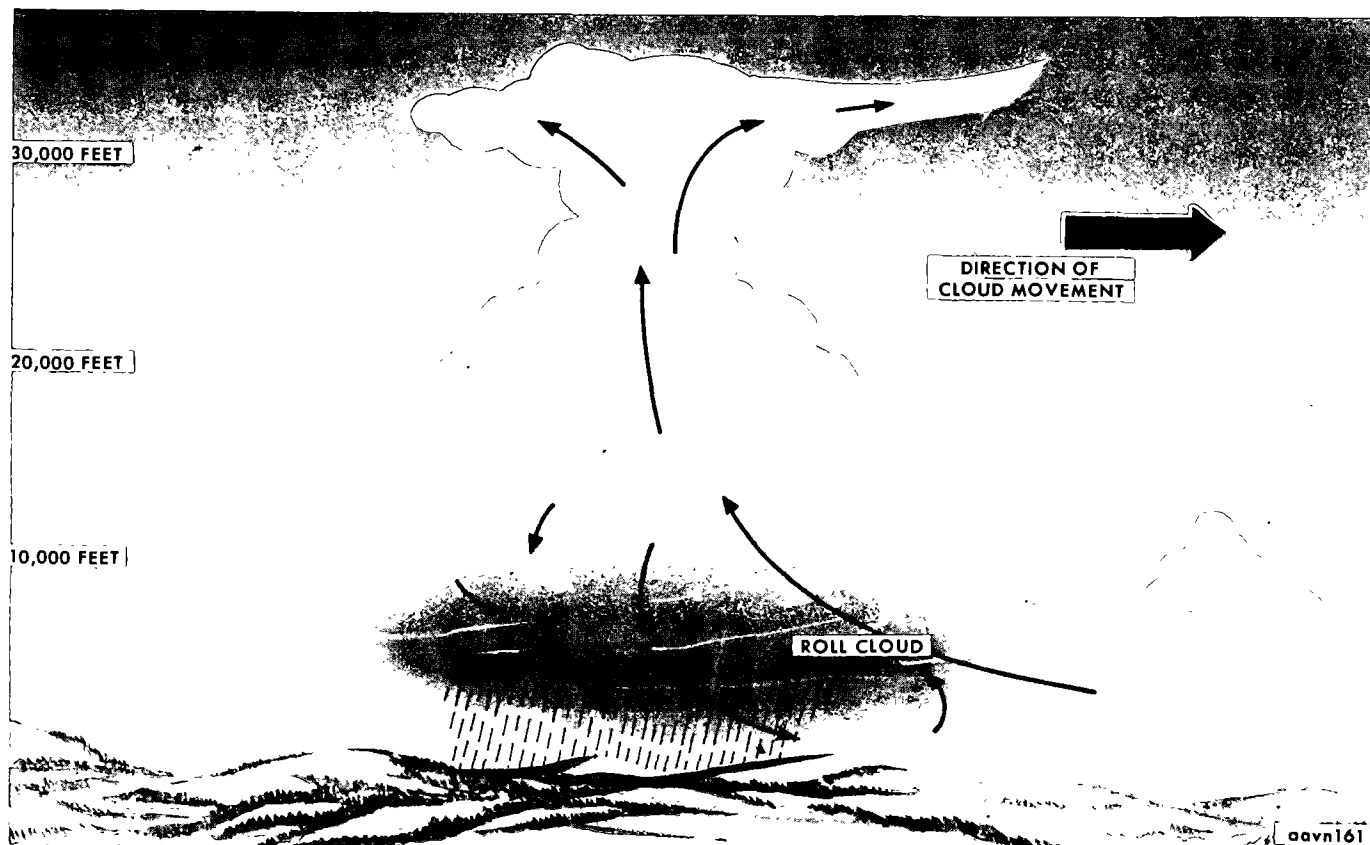


Figure 10-1. Thunderstorm (cumulonimbus) cloud.

relatively high moisture content and some type of lifting action.

a. Conditional Instability. Conditional instability exists when the temperature lapse rate of the air involved lies between the moist and dry adiabatic rates of cooling. Before the displaced air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this point has been reached, the relatively warmer air continues to rise freely until, at some higher altitude, its temperature has cooled to the temperature of the surrounding air. In the instability process, numerous variables tend to modify the air. One of the most important of these variables is the process called *entrainment*. In this process, air adjacent to the cumulus or mature thunderstorm is drawn into the cloud, primarily by strong updrafts within the cloud. The entrained air modifies the temperature of the air within the cloud as the two become mixed.

b. Lifting Action. Some type of external lifting action is necessary to bring the warm surface air to the point where it will continue to rise freely (the level of free convection). For example, an air mass may be lifted by thermal convection, terrain, fronts, or convergence.

c. Moisture. Warm air lifted upslope may not cause free convection. Air may be lifted to a point where the moisture condenses and clouds form, but these cloud layers will be stable if the level of free convection has not been reached by the lifting. Conversely, it is possible for dry heated air to rise convectively without the formation of clouds; in this condition, turbulence might be experienced in perfectly clear weather. Cumulonimbus cloud formations require a combination of conditionally unstable air, some type of lifting action, and high moisture content. Once a cloud has formed, the latent heat of condensation released by the change of state from vapor to liquid tends to make the air more unstable.

10-3. Frontal Thunderstorms

Thunderstorms may occur within the cloud system of any front—*warm, cold, stationary, or occluded*. Frontal thunderstorms are caused by the lifting of warm, moist, conditionally unstable air over a frontal surface. Thunderstorms may also occur many miles ahead of a rapidly moving cold front. The direct cause of these *prefrontal* thunderstorms is uncertain, but they are associated with frontal weather and weaken the thunderstorm activity along the cold frontal surface.

a. Warm-Front Thunderstorms. These thunderstorms are caused when warm, moist, conditionally unstable air is forced aloft over a colder, more dense shelf of retreating air. Because the frontal surface is very shallow, the air is lifted gradually. The lifting

condensation level is normally reached long before the level of free convection, thus producing stratiform clouds. The level of free convection will normally be reached in isolated areas along the frontal surface where the greatest amounts of water vapor are present in the warm air being lifted. Therefore, warm-front storms are generally scattered. Once the level of free convection is reached, warm-front thunderstorms may form. These storms are extremely difficult to identify because they are obscured by the surrounding stratiform clouds. The aviator, however, may be warned of such a condition by loud crashes of static in his earphones (para 10-7e) when using his low or medium frequency receiver. A study of the Skew T, log p. diagram for stations along the proposed flight route often aids the aviator by warning him of the existence of a conditionally unstable lapse rate through the layers of atmosphere in which clouds are forming (fig 10-2 and 10-3). By referring to the radar summary charts, the aviator can determine the presence and nature of buildups (para 15-6).

b. Cold-Front Thunderstorms. The forward motion of a wedge of cold air under a mass of warm, moist, conditionally unstable air (cold front) causes thunderstorms to develop. The slope of a typical cold frontal surface is relatively steep (fig 10-4), so the lifting condensation level and the level of free convection are usually near the same altitude. Cold-front thunderstorms are typically positioned along the frontal surface in what appears to be a continuous line. These storms are easily recognized from the air because they are partly visible from the front and rear of the storm line. However, if the slope of the frontal surface is shallow (fig 10-5), the lifting action is not sufficient to produce thunderstorms in lines (line squalls). With a shallow front, the thunderstorms form behind the surface front and are widely scattered. Such storms may be concealed by the surrounding cloud layers.

c. Prefrontal Squall-Line Thunderstorms. Frequently, with a rapidly moving cold front, lines of thunderstorms may develop ahead of the cold front. These are known as prefrontal squall lines, and frequently form parallel to the cold front (fig 10-6 and 10-7). Prefrontal squall-line thunderstorms are usually more violent than cold-front thunderstorms and are most active between noon and midnight. The cold-front cloud system usually weakens during the period of the greatest prefrontal squall-line activity, because the warm air displaced by the frontal surface has lost its moisture and energy in the prefrontal thunderstorms. In the United States, tornadoes are frequently associated with strong prefrontal squall lines. Prefrontal squall-line thunderstorms are indicated on the surface weather map by an alternate dash-dot-dot line.

d. Stationary-Front Thunderstorms. The distribu-

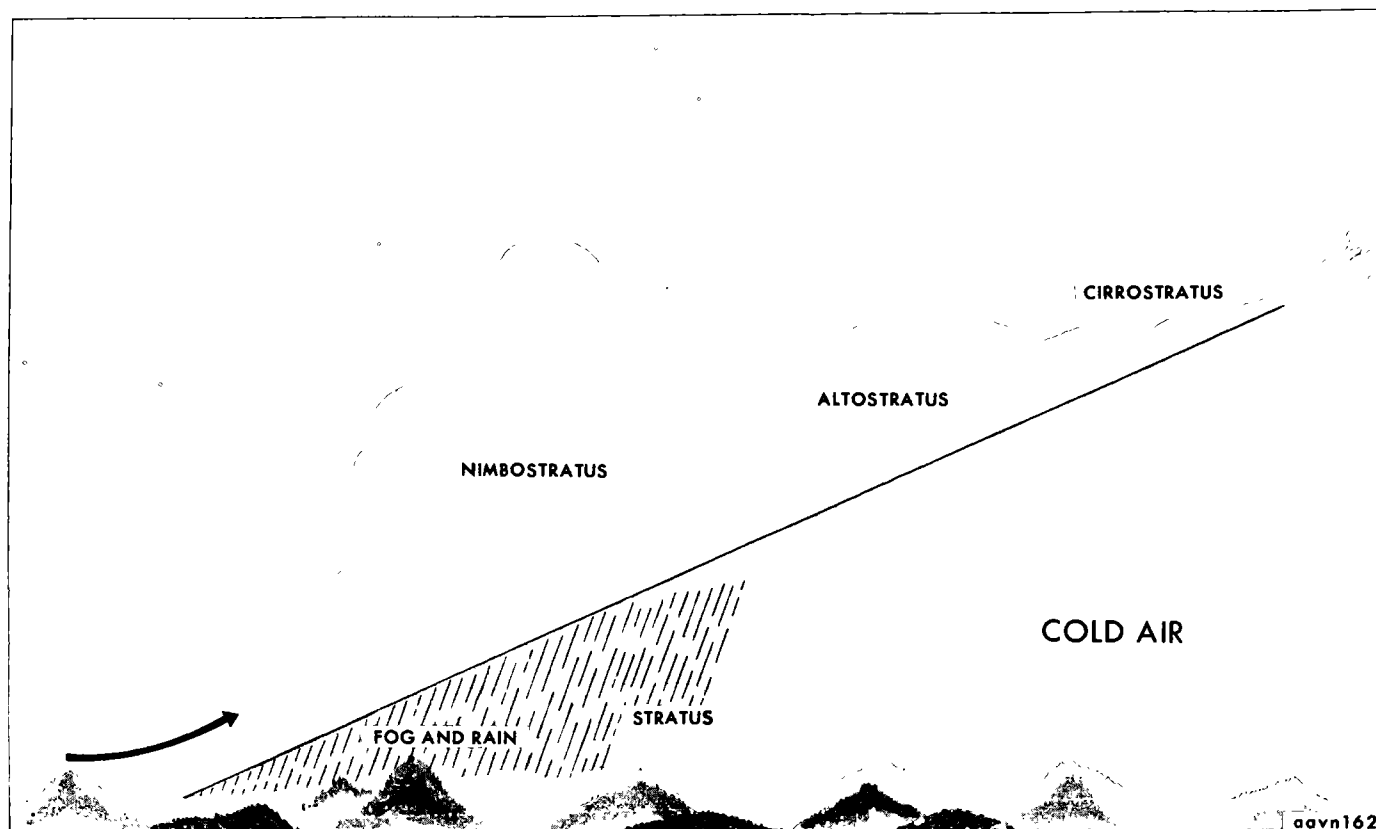


Figure 10-2. Warm front (stable warm air).

tion of these thunderstorms is controlled by the slope of the frontal surface. Steeply sloped stationary fronts tend to have lines of storms, whereas shallow stationary fronts tend to have the storms widely scattered.

e. Occluded-Front Thunderstorms. Thunderstorms associated with the two types of occluded fronts (warm front and cold front occlusions) are usually cold-front thunderstorms that have been moved into the area of warm frontal weather by the occlusion process (para 7-5a, c). They are found along the upper front and are normally strongest for a distance of 50 to 100 miles north of the peak of the warm sector.

10-4. Air Mass Thunderstorms

The two types of air mass thunderstorms are locally *convective* and *orographic*. Both types form within air masses and are typically randomly distributed throughout the airmass (fig 10-8).

a. Convective Thunderstorms. Convective thunderstorms are often caused by solar heating of the land which, in turn, provides heat to the air, resulting in thermal convection. Relatively cool air flowing over a warmer water surface may also produce sufficient convection to cause thunderstorms.

(1) The land-type convective thunderstorms normally form during the afternoon hours after the earth has gained maximum heating from the sun. If cool,

moist, conditionally unstable air is passing over this land area, heating from below will cause convective currents and result in towering cumulus or thunderstorm activity (fig 10-9). Dissipation usually occurs during the early evening hours as the land begins to lose its heat to the atmosphere. Although convective thunderstorms form as individual cells, they may become so numerous over a particular geographical area that VFR flight is impossible. These areas of congested cumulus and cumulonimbus clouds should break and dissipate in approximately 2 hours.

(2) Thunderstorms over the ocean are most common during the night and early morning. They frequently occur offshore when the land and sea breezes are blowing toward the water. The cool land breeze is heated by the warmer water surface, resulting in sufficient convection to produce thunderstorms. After sunrise, heating of the land surface reverses the airflow (sea breeze). The thunderstorms then dissipate over the water but re-form over the warmer land surface.

(3) The air mass weather that exists in Florida combines both types of convective thunderstorms (fig 10-10). Circulation around the Bermuda High carries moist ocean air over the warm land surface of the Florida peninsula. At night, thunderstorms off the Florida coast are caused by the warm water of the Gulf Stream heating the surface air while the upper

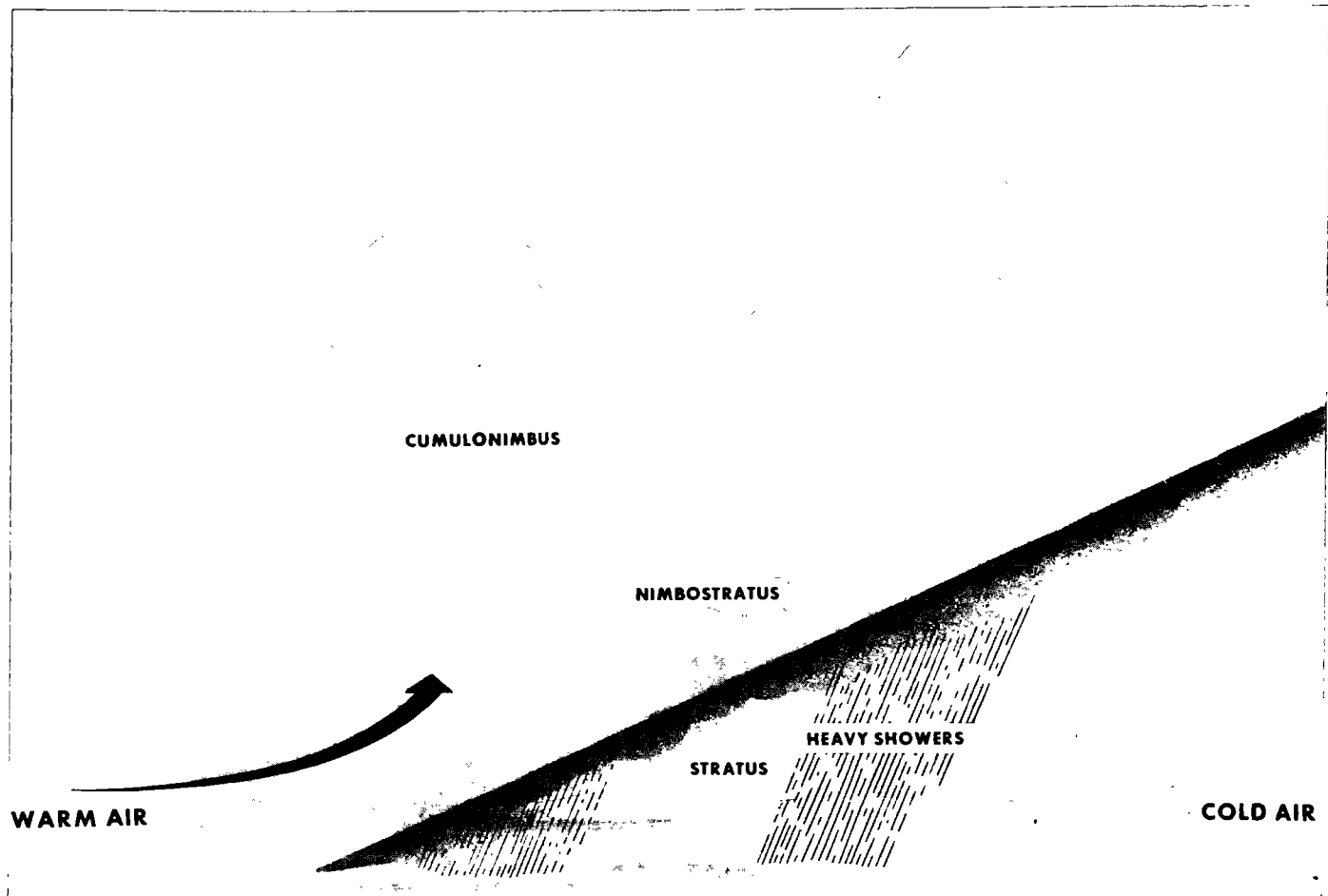


Figure 10-3. Warm front (conditionally unstable warm air).

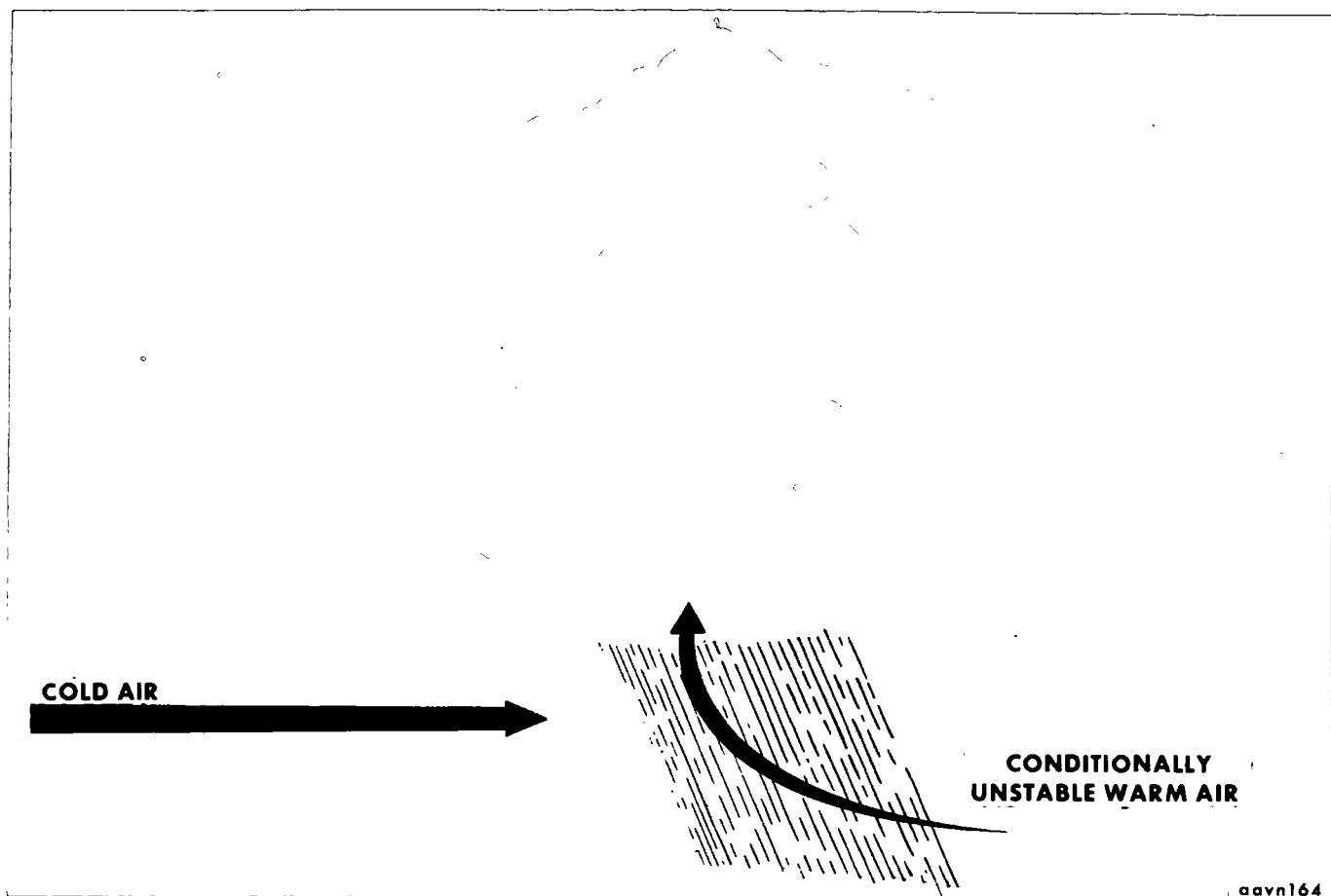
air is cooling by radiation to space. This heating from below produces thermal convection over the water. When the sun rises, the heat balance necessary to maintain storm formation over the water is destroyed. By day, the storms appear to move inward over the land areas, but actually dissipate off the coast and re-form over the hot land mass. The heated land surface sets up an unstable lapse rate over the peninsula and causes storm development to continue until nocturnal cooling occurs. Usually, convective type storms are randomly distributed and easily recognized. The visibility in the areas surrounding the clouds is generally excellent (fig 10-10).

b. Orographic Thunderstorms. Thunderstorms will form on the windward side of a mountain if conditionally unstable air is lifted above the level of free convection. The storm activity is usually scattered along the individual peaks of the mountains, but occasionally it may form a long unbroken line of storms similar to a squall line. The storms persist as long as the circulation causes upslope motion. From the windward side of the mountains, identification of orographic storms may sometimes be difficult because the storm clouds are obscured by other clouds

(usually stratiform) below the level of free convection. Almost without exception, orographic thunderstorms enshroud mountain peaks or hills. No attempt should be made to fly under this type of storm unless the opposite side of the area is clearly visible to the aviator and considerable altitude is available between the terrain and the cloud bases (fig 10-11).

10-5. Structure of Thunderstorms

a. Convective Cells. The fundamental structural element of the thunderstorm is the unit of convective circulation known as a *convective cell*. A mature thunderstorm contains one or more of these cells in different stages of development, each varying in diameter from 1 to 5 miles. By radar analysis and measurement of drafts, it has been determined that each cell is generally independent of surrounding cells in the same storm. Each thunderstorm progresses through a life cycle of from 1 to 3 hours, depending upon the number of cells contained and their stage of development. In the initial stage (cumulus), the cloud consists of a single cell; as the development progresses, new cells may form as older cells dissipate.



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Figure 10-4. Abrupt cold front (conditionally unstable warm air).

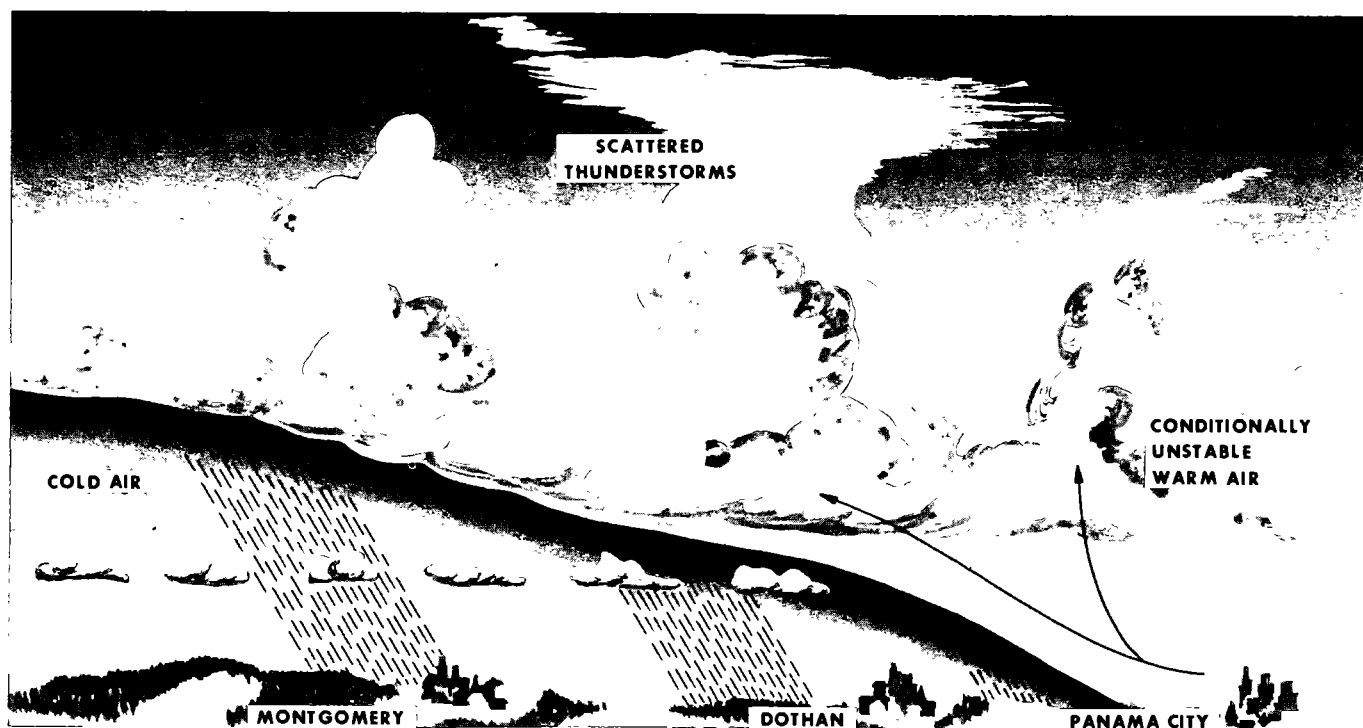


Figure 10-5. Shallow cold front. (conditionally unstable warm air).



Figure 10-6. Squall-line clouds.

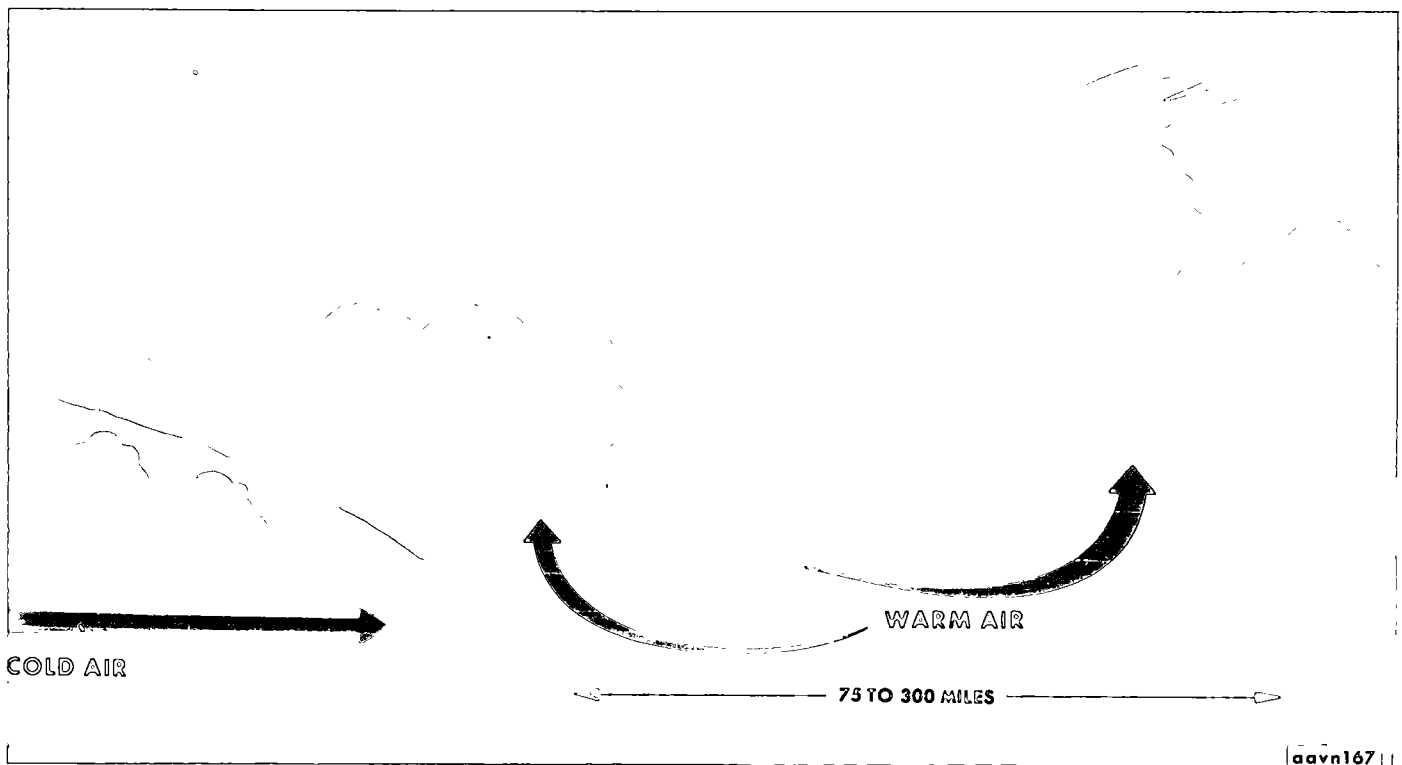


Figure 10-7. Prefrontal squall line.



Figure 10-8. Air mass thunderstorms.

b. Stages in Cell Development. The life cycle of each thunderstorm cell consists of three distinct stages: *cumulus*, *mature*, and *dissipating or anvil*.

(1) *Cumulus stage.* Although most cumulus clouds do not become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The chief distinguishing feature of the cumulus or building stage is an updraft which prevails throughout the entire cell (fig 10-12). This updraft may vary from a few feet per second to as much as 100 feet per second (65 knots) in mature cells. As an updraft continues through the vertical extent of the cell, water droplets coalesce, and raindrops are formed.

(2) *Mature stage.* The beginning of surface rain and adjacent updrafts and downdrafts initiates the mature stage (fig 10-13). By this time, the average cell has attained a height of 25,000 feet. As the drops begin to fall, the surrounding air begins a downward motion. Being unstable, this air becomes colder than its surroundings and its rate of downward motion is accelerated, forming the *downdraft*. The downdraft reaches maximum speed a short time after rain be-

gins to fall in the cloud. Downdrafts occur at all levels within the storm and their speed ranges from a few feet per second to about 40 feet per second (25 knots). Significant downdrafts never extend to the top of the cell because moisture is not sufficient in the upper levels for raindrops to form. At these high levels only ice crystals and snowflakes are present, and their rate of fall is insufficient to cause appreciable downdrafts. The mature cell generally extends far above 25,000 feet—in rare instances up to 70,000 feet. In the middle levels, around 14,000 feet, strong updrafts and downdrafts are adjacent to each other. Their friction causes a shear action between the drafts and produces strong and frequent gusts. These gusts may easily flip the aircraft into unusual attitudes and overstress its structure especially during middle-altitude penetrations.

(3) *Dissipating or anvil stage.* Throughout the life span of the mature cell, more and more air aloft is entrained by the falling raindrops. Consequently, the downdraft spreads out to take the place of the weakening updrafts. As this process progresses, the

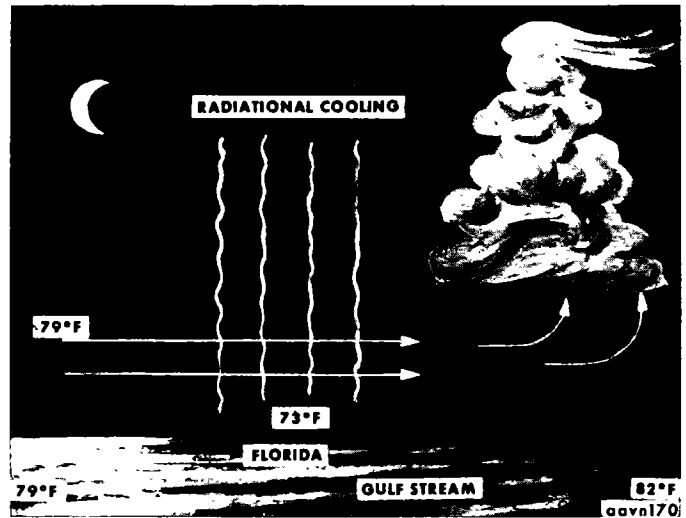
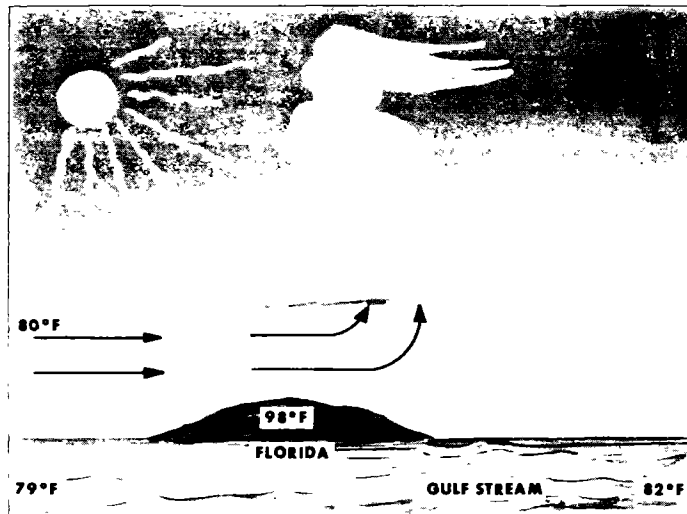


Figure 10-10. Daily variations of coastal thunderstorms.

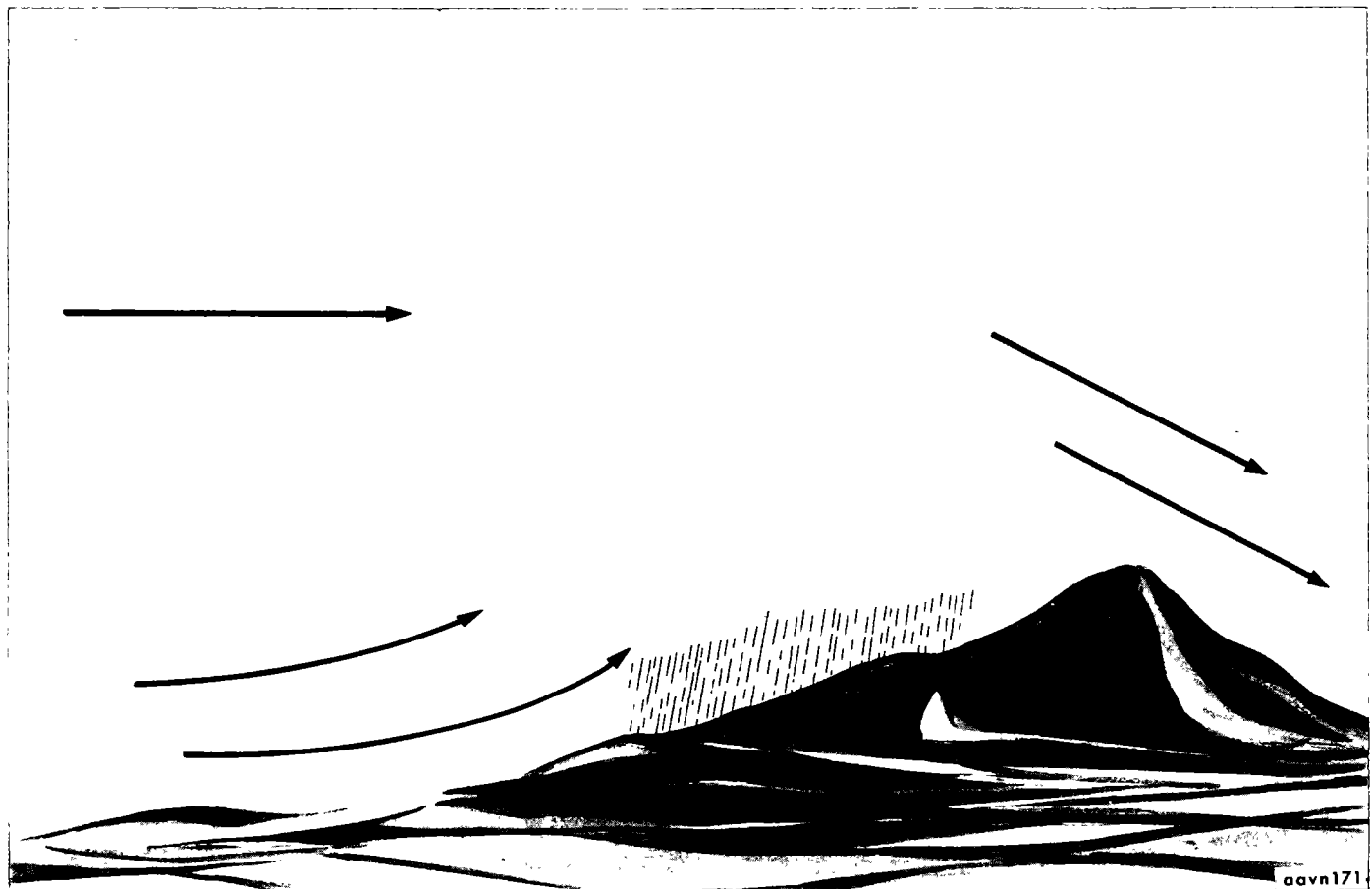


Figure 10-11. Orographic (upslope) thunderstorm.

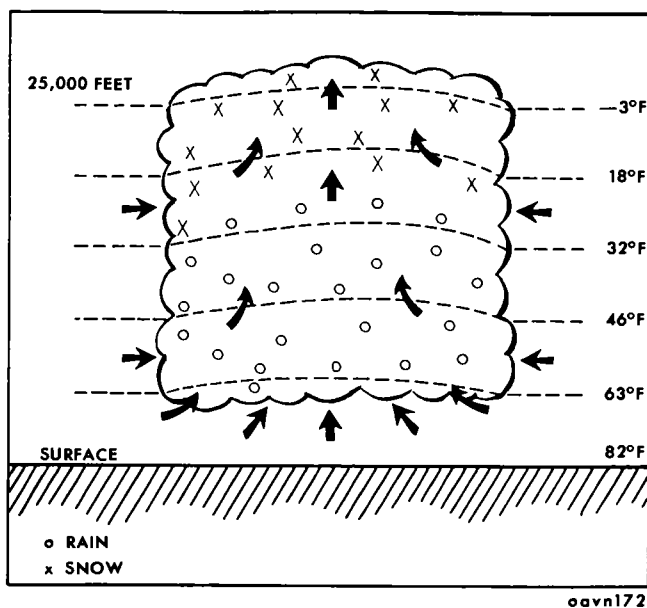


Figure 10-12. Thunderstorm cell, cumulus stage.

entire lower portion of the cell becomes an area of downdraft. Since updrafts are necessary to produce condensation and latent heat energy, the entire structure begins to dissipate. The strong winds aloft carry the upper section of the cloud into the familiar anvil form (cumulonimbus cloud), indicating that the storm cell is gradually dissipating (fig 10-14).

10-6. Vertical Development

The height of storms is of great concern to the aviator determining an optimum flight altitude. Prior to the advent of radar analysis, accurate estimates of cumulonimbus cloud tops were difficult because of stratified cloud shelves at lower levels.

a. Measurements. Measurements of the vertical extent of thunderstorm activity have been made in various projects by use of radar. The average height

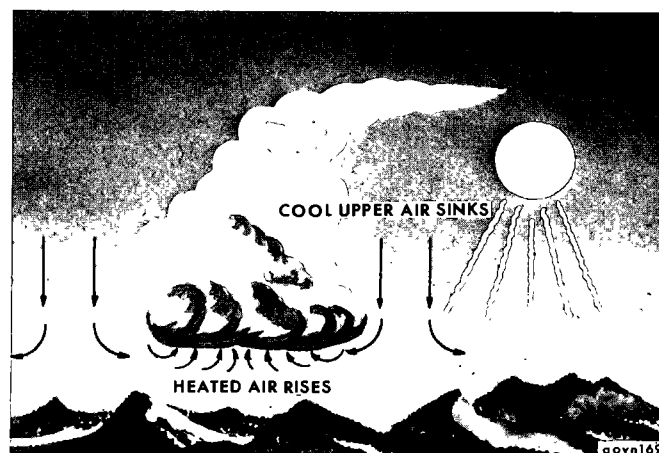


Figure 10-9. Locally convective thunderstorms.

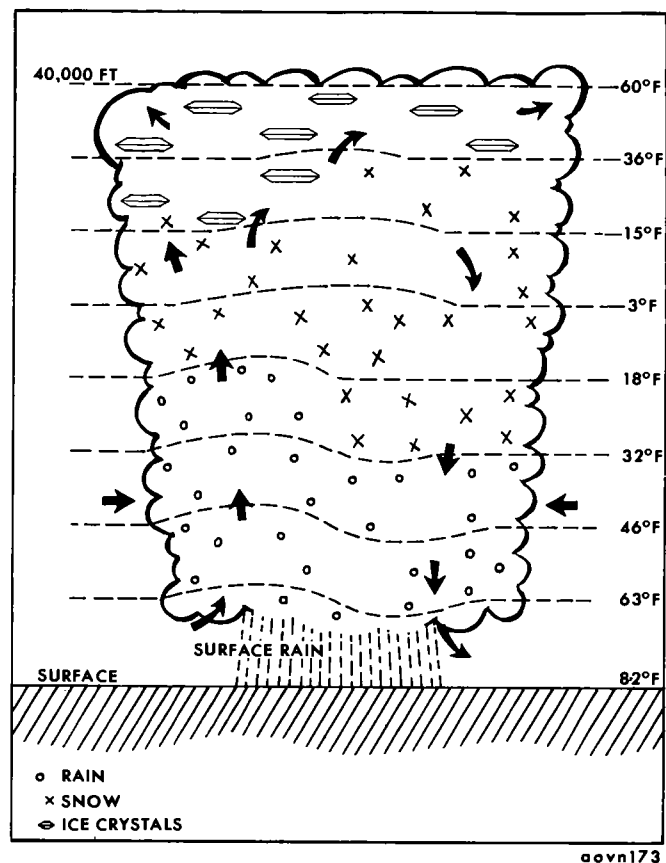


Figure 10-13. Thunderstorm cell, mature stage.

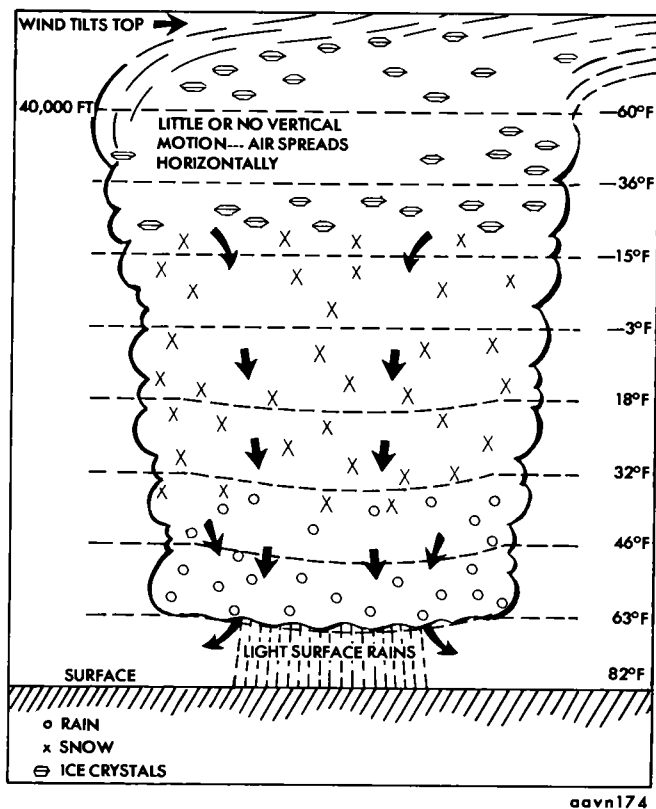


Figure 10-14. Thunderstorm cell, dissipating stage.

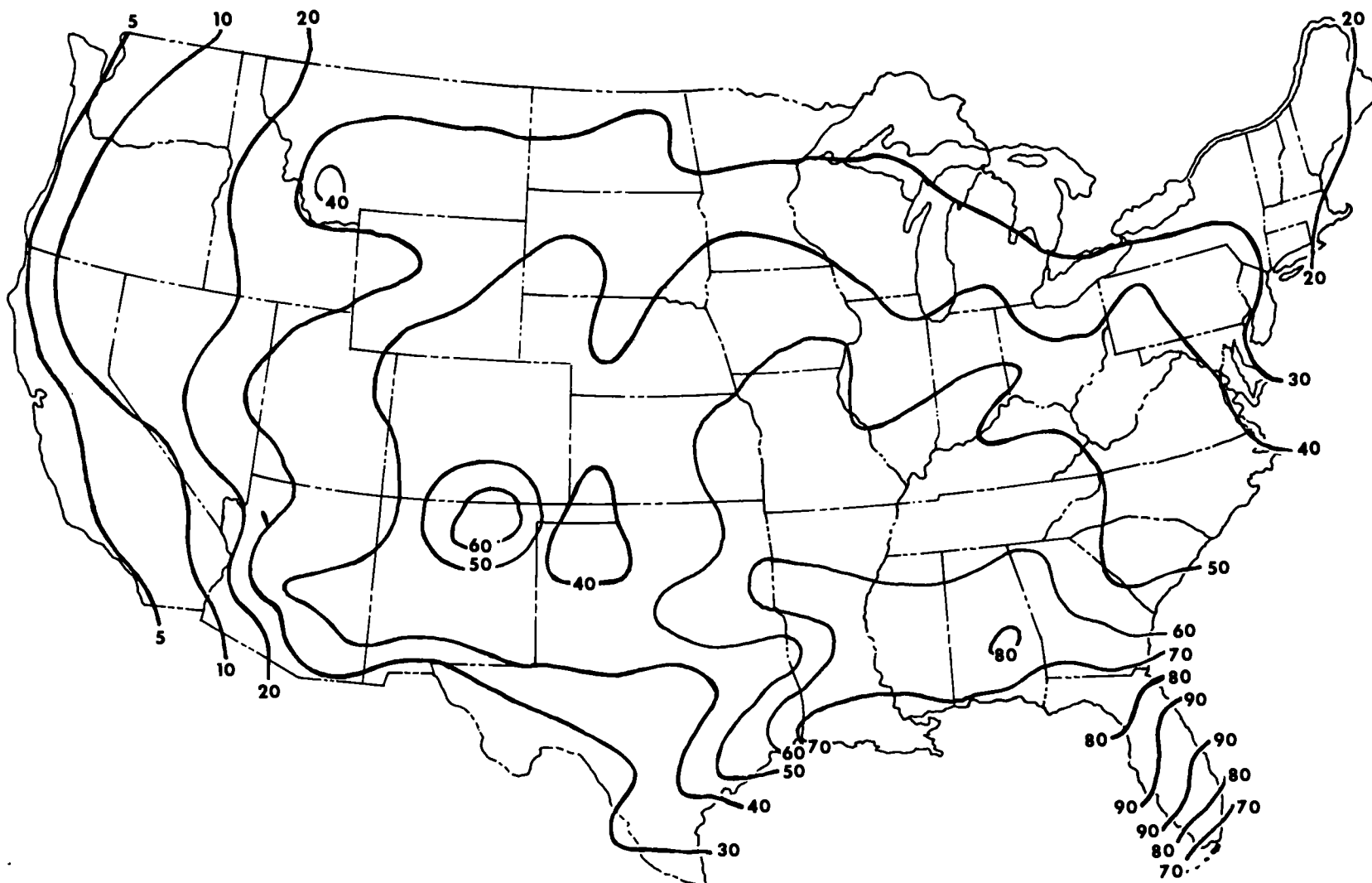


Figure 10-15. Average number of thunderstorms each year over the conterminous United States.

measured was 37,000 feet, and the maximum height observed was 56,000 feet. Severe storms attain heights greater than this. The average number of thunderstorms over the conterminous United States is shown in figure 10-15.

Note. The Thunderstorm Project was a joint Weather Bureau-Air Force-Navy-N.A.C.A. project conducted from 1946 through 1949. A more recent study, Project "ROUGH RIDER" was a combined effort of the National Severe Storm Laboratory, FAA, NASA, and the US Air Force.

b. Drafts and Gusts Defined. Rising and descending drafts of air form the structural basis of the thunderstorm cell. A *draft* is a large vertical current which is continuous over many thousands of feet of altitude. Speeds of such drafts may either be constant or gradually varying from one altitude to the next. *Gusts* are smaller currents generally caused by a shearing action between the drafts. Individual gusts have a very short horizontal and vertical extent, but these gusts actually cause the severe bumpiness in flight. A draft may be compared to a large river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or any other random motion of water within the main current.

c. Drafts. Considerable data on drafts was collected and tabulated in various studies concerning the speed of drafts and the effects of drafts on aircraft. Measurements of drafts were computed from changes in pressure altitudes. No effort was made by the pilot to maintain altitude during the measurements. Results are given below.

(1) The maximum updrafts were found in the middle and upper levels of the storms.

(2) The mean of updraft and downdraft velocities increased with height.

(3) Updrafts were generally of greater velocity than downdrafts.

(4) Greater aircraft displacement was observed at the middle levels. An airplane flying at 130 knots at 14,000 feet suffered a displacement of approximately 6,000 feet in 70 seconds, whereas similar aircraft flying at the same airspeed at the 6,000-foot level experienced maximum displacement of only 1,600 feet.

(5) In the middle and upper levels of the cell, mean displacement caused by updrafts was greater in all cases than mean displacement caused by downdrafts.

(6) In no case was an aircraft flying at the 5,000- to 6,000-foot level brought dangerously close to the ground by a downdraft (uneven terrain areas excepted).

d. Gusts. Turbulent motions within the cellular circulation pattern of thunderstorms have considerable effect upon an aircraft. In fact, the severity

of a storm may be classified by the intensity and frequency of its gusts. The eddies, which are typical of thunderstorm gustiness, vary in size from only a few inches to whirling masses several hundred feet in diameter. The characteristic reaction of an aircraft intercepting a series of gusts is a number of sharp accelerations or "bumps" without significant change in altitude. These accelerations may be accompanied by pitch, yaw, or roll movements and are caused by abrupt changes in the wind field encountered by the aircraft. The degree of "bumpiness" experienced in flight is related both to the number of such abrupt changes encountered in a given distance and the strength of the individual changes.

(1) Comparison of aviator reports of turbulence during flights has shown that gusts occurring with a greater frequency than six per 3,000-foot interval of flight are associated with extreme turbulence.

(2) Light gust speeds were more frequent throughout the storm than those of higher velocity.

(3) The high velocity gusts (24 feet per second or greater) were also observed at all altitudes, but with far less frequency.

(4) Since gusts of all speeds are prevalent at all altitudes, they cannot be avoided in flight; however, there is a definite maximum frequency of the higher speed gusts in the vicinity of 15,000 feet, usually near the freezing level.

(5) Gusts as strong as 43 feet per second (27 knots) have been measured during thunderstorm penetrations. (It is highly probable that gusts greatly exceeding these measurements exist.) High-speed gusts have caused structural deformation and even structural failure, but in most of these cases, it is believed that the strong gusts were encountered at an incorrect airspeed for the particular aircraft.

(6) Since the greatest frequency of strong gusts was observed at the 15,000-foot level (usually near the freezing level), this level should be avoided when thunderstorm penetration becomes necessary. Strong gusts may also be encountered at other altitudes in the storm, and in a few cases severe and/or extreme turbulence has been encountered in clear air above, or out to 5 miles laterally from, developing mature thunderstorms.

10-7. Weather Within the Storm

a. Rain. Upon entering a thunderstorm, the aviator can expect to encounter considerable quantities of water droplets. This moisture is not necessarily falling to the ground as rain. It may be suspended in or moving with the updrafts. Rain is encountered below the freezing level in most penetrations of fully developed thunderstorms. Above the freezing level, there is a sharp decline in the frequency of rain. Clouds causing intense precipitation also have strong turbulence within them.

b. Hail.

(1) During the Thunderstorm Project (para 10-6a), hail was encountered at a maximum of 10 percent of the traverses at a given altitude. It was seldom found at more than two levels in the same storm. When it was observed, its duration was very short. All intensities of hail reached maximum occurrence at the middle altitudes.

(2) Hail has also been encountered outside the storm cloud. The hailstones may be thrown upward and outward from the cloud under the anvil as much as 10 miles or more. Many thunderstorm clouds contain hail which may never reach the surface.

c. *Icing.* Clear icing in cumulus clouds and thunderstorms is usually limited in extent because of the cellular structure of the clouds, but may occasionally be very severe. The severest icing conditions usually occur just above the freezing level where the greatest concentration of supercooled water droplets exists. Within the cloud, severe icing may occur at any point above the freezing level. Since the freezing level is also the zone where heavy turbulence and rainfall most frequently occur, this particular altitude appears to be the most hazardous.

d. *Snow.* During various projects, the maximum frequency of moderate and heavy snow occurred at the 20,000- and 21,000-foot levels. In many cases, a mixture of snow with supercooled raindrops was encountered at all altitudes above the freezing level. A unique icing problem was created by the accumulation of wet snow on leading edges of the aircraft and the resultant rapid accumulation of rime ice.

e. Electricity.

(1) *Lightning.* Observations of the atmosphere during periods of fair weather show that the earth normally has a negative electrical charge with respect to the air above it. With the development of a thunderstorm, the electrical charge in the atmosphere is redistributed in such a manner as to make the upper portion of the thunderstorm cloud positive and the lower portion negative. This in turn induces a positive charge on the ground, reversing the fair weather electric field in the lower levels and producing the distribution of electrical charges shown in figure 10-16.

- The center of the negative charge is generally located between the freezing level and the -10° C. level, while the positive charge center is located near the -10° C. level. As the thunderstorm progresses through the mature stage, a small region of positive charge also develops in the downdraft associated with the heaviest rain.

- Lightning develops in the region between the upper positive charge center and the negative charge center, sometimes called the "lightning hearth region." The lightning is apparently associated with the existence of both water droplets and crystals of

ice and snow at the same level—the exact physical origin of lightning is very complex and beyond the scope of this manual.

- Lightning is most frequently encountered as discharges from cloud to cloud or within a cloud, but it may also occur from cloud to ground or ground to cloud. The estimated total potential required to produce a lightning stroke 10,000 feet long is 20 to 30 million volts. Its current may vary from 60,000 to 100,000 amperes. The frequency of lightning is greatest at the time the thunderstorm cell reaches its maximum height, just prior to the time of maximum rainfall at the surface.

- Since lightning may damage an aircraft, the aviator should avoid thunderstorm areas where lightning is most frequent. Lightning strikes are least frequent at the lowest flight levels.

- Lightning discharges cause loud crashes of static on low- and medium-frequency radio receivers. This static affects radio communication throughout a distance of many miles from its thunderstorm source.

(2) *Precipitation static.* Static electricity is encountered more frequently by aircraft in thunderstorms than are lightning strikes. Two safeguards the aviator can provide against precipitation static are to reduce speed or change altitude.

- The *brush* or *corona discharge* is produced when an aircraft in flight accumulates pronounced static charges through contact with ice crystals and dust. The accumulation discharges to the surroundings and causes precipitation static in the aircraft radio receiver. Low- and medium-frequency radio reception may become impossible under such circumstances.

- On other occasions, an induced charge on the aircraft fuselage tends to strengthen the effect of the electric field in the cloud, and the resulting lightning discharge may use the airplane as a part of the conducting path. External electric fields strong enough to induce localized charges in the aircraft are usually associated with areas of strong updrafts and downdrafts in the thunderstorm. The greater the turbulence, the larger the associated external fields are likely to be.

- Strong external fields also exist in cloud regions where supercooled water droplets and ice crystals co-exist. The production of negative charges is very common near the freezing level within the storm, and in the tops of the clouds where ice crystals are forming.

- External fields are also found in precipitation areas below the clouds and are generally strong in areas of heavy precipitation.

f. *First Gusts.* Another significant thunderstorm hazard is the rapid change in wind direction and speed immediately prior to storm passage at the surface. These strong winds are the result of the horizontal spreading of the storm's downdraft currents as

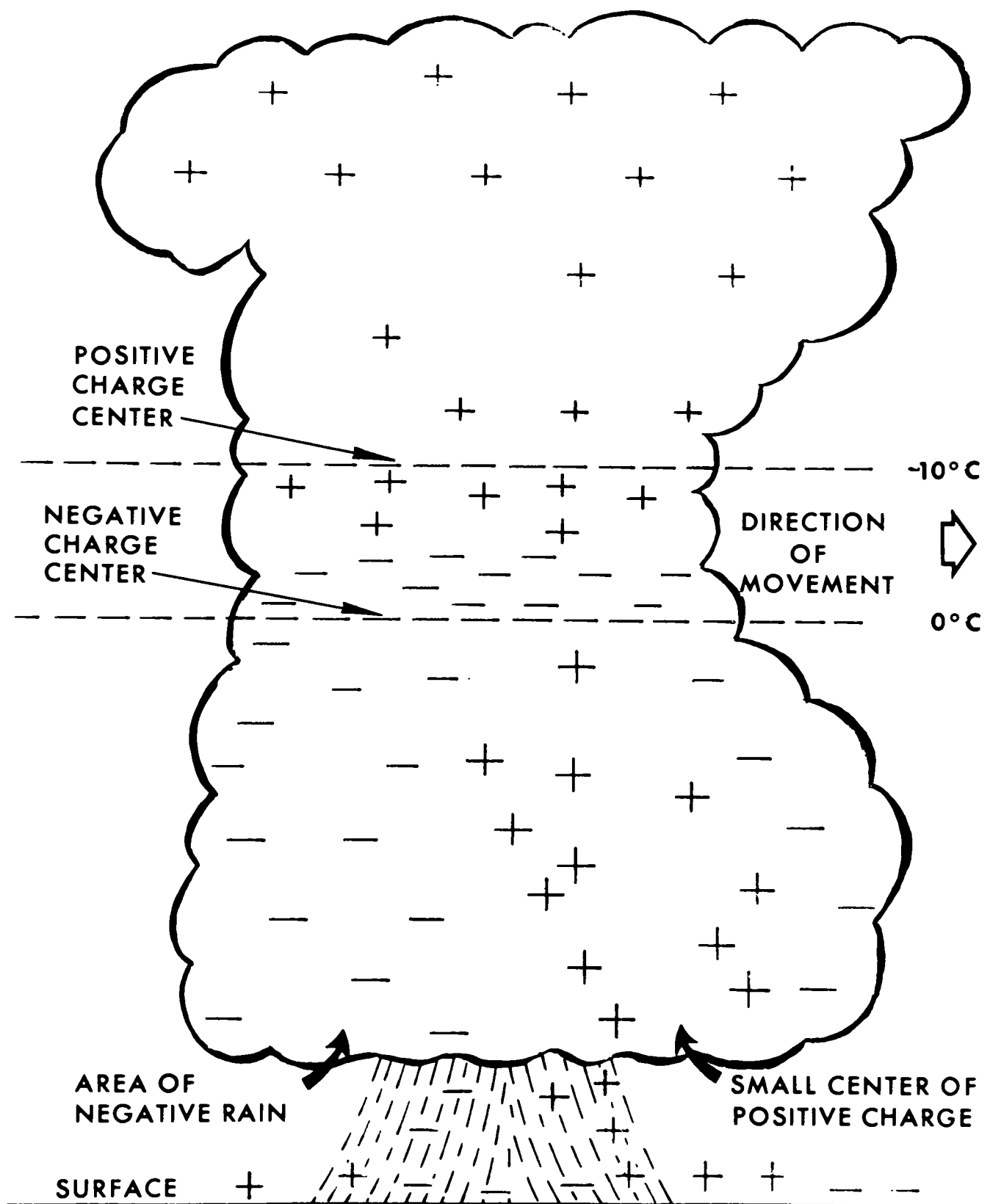


Figure 10-16. Location of electrical charges inside a typical thunderstorm cell.

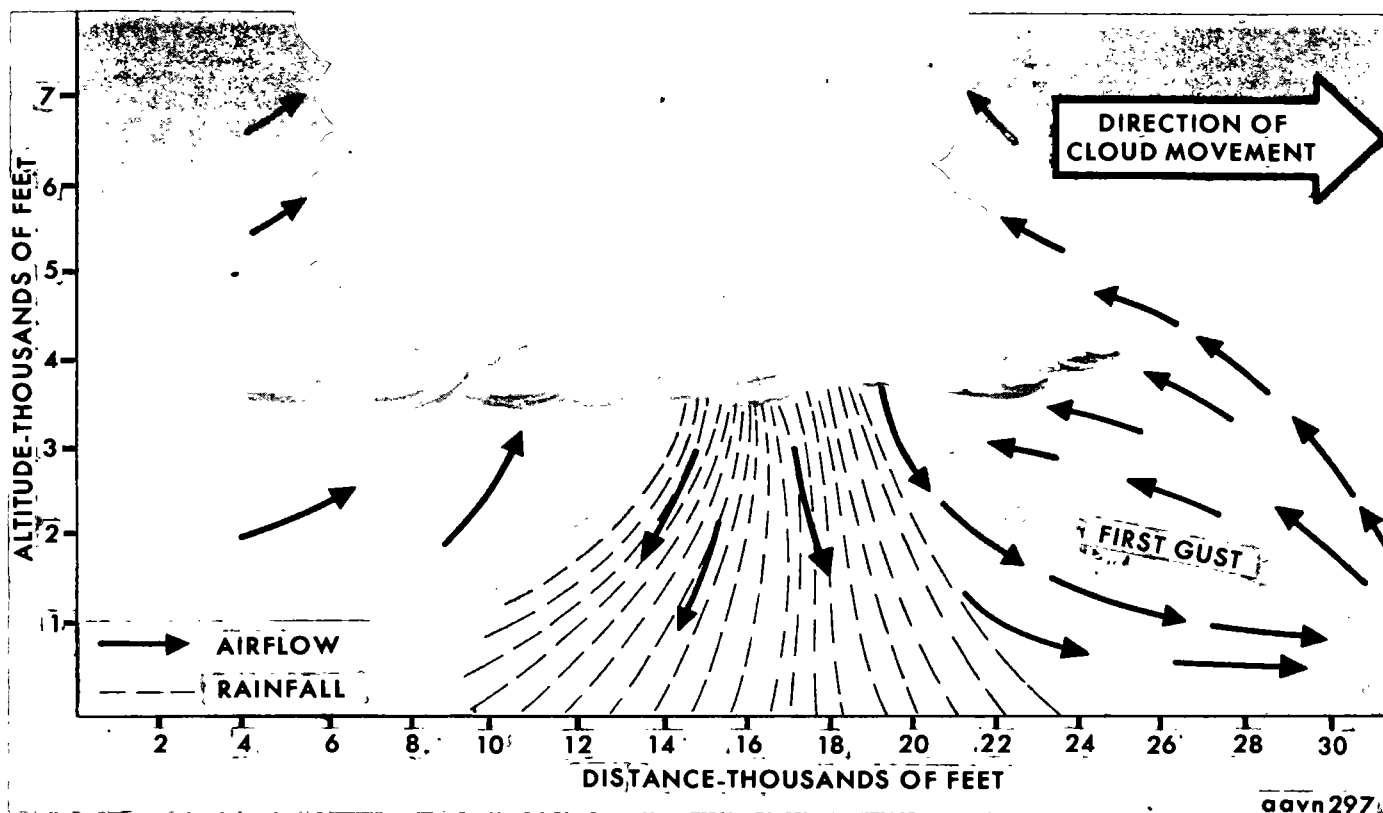


Figure 10-17. Air movement beneath a thunderstorm cell in the mature stage.

they approach the surface of the earth. The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge of the storm are far greater than those at the trailing edge. This initial wind surge, as observed at the surface, is known as a *first gust*. The speed of this first gust may exceed 75 knots and vary 180° in direction from the previously prevailing surface winds. First-gust speeds average about 15 knots over prevailing velocities, and average about 40° change in direction of the wind. First gusts usually precede the heavy precipitation and strong gusts may continue for approximately 5 to 10 minutes with each thunderstorm cell (fig 10-17).

g. Pressure Variations. During the passage of a thunderstorm, rapid and marked surface pressure variations generally occur. These variations usually occur in a particular sequence characterized—(1) an abrupt fall in pressure as the storm approaches, (2) an abrupt rise in pressure associated with rain showers as the storm moves overhead, and (3) a gradual return to normal pressure as the storm moves on and the rain ceases. Such pressure changes may result in significant altimeter errors if the altimeter setting is not corrected. During the “Thunderstorm Project,” for each of the days on which one or more thunderstorms occurred, the maximum pressure rise and fall were converted to the equivalent altimeter error and tabulated. In 22 percent of the

cases an altimeter setting 10 to 15 minutes old would have resulted in an error of 60 feet or more in the altimeter indication. If an aviator used an altimeter setting obtained during the time of maximum pressure and landed after the pressure had fallen, on 26 percent of the days his altimeter would have read 60 feet or more above the true altitude after he was on the ground. On two occasions, the altimeter would have read over 140 feet above the true altitude when he landed.

h. Ceiling and Visibility. Ceiling and visibility in the precipitation areas under the thunderstorms are normally poor. Because of the heavy precipitation, the ceiling reported is at best an estimate of where the aviator may break out into visual contact with the surface. The weather observer determines the vertical visibility into the precipitation, and this may be significantly different from the slant-range visibility of the aviator. With normal altimeter error and a gusty surface wind condition, the restrictions to visibility and low ceiling associated with the thunderstorm present a further hazard to the landing of aircraft.

i. Turbulence (All Types).

(1) *Empirical classification.* Turbulence is the effect of updrafts, downdrafts, and gusts on aircraft in flight. The degree or intensity of turbulence in the atmosphere is classified into four categories.

- *Light turbulence.* Light turbulence may occur at any altitude and usually covers an extensive area. It is typically encountered during flights through small afternoon cumulus clouds; at low altitudes over rough terrain when the surface wind speeds are less than 25 knots; and flights at low altitudes over unequally heated land areas during the period of maximum heating or over warm water surfaces at night.

- *Moderate turbulence.* Moderate turbulence is typically encountered in the mountain wave up to 150 miles on the lee side of the mountains when the wind is perpendicular to the mountain range at speeds from 25 to 50 knots at ridge level, and at lower altitudes when the surface winds exceed 25 knots. It is frequently encountered around and above thunderstorms or in the cirrus tops of cumulonimbus clouds; 5,000 feet above or below the jet stream core, or in areas of jet stream cirrus clouds; in towering cumulus clouds; and in unstable air which is too dry to produce cumuliform clouds of great vertical extent. Moderate turbulence may also occur with upper troughs, cold-core low pressure systems, fronts aloft, or in areas where the wind shear is at least 6 knots per 1,000 feet vertically or 10 knots per 100 miles horizontally.

- *Severe turbulence.* Severe turbulence is usually encountered in the mountain wave as much as 50 miles to the lee of the mountains when the winds are perpendicular to the mountain range at speeds from 20 to 50 knots at ridge level, and within mature thunderstorms. It may occasionally be encountered in jet streams or towering cumulus clouds.

- *Extreme turbulence.* Extreme turbulence is the strongest form of convection. It is typically encountered in the roll cloud of the mountain wave when winds are perpendicular to the mountain range at speeds exceeding 50 knots at ridge level, and with standing wave action or strong wind shear. It is frequently associated with growing thunderstorm cells where hail, heavy rainshowers, or heavy thunder is reported.

(2) *In-flight classification.* Another method of classifying turbulence is with regard to its effect on the aircraft in flight. This classification may be useful to the aviator in reporting turbulence and its effect on his particular aircraft.

- *Light turbulence.* Light turbulence may require the use of seat belts. It produces a variation in airspeed from 5 to 15 knots. Loose objects in the aircraft remain at rest during flight.

- *Moderate turbulence.* Moderate turbulence requires the use of seat belts. Airspeed is affected, varying from 15 to 25 knots. Objects loose in the aircraft tend to slide or roll.

- *Severe turbulence.* Severe turbulence causes the aviator to lose control of the aircraft momentarily. The occupants are thrown violently against

seat belts and the seat. Loose objects are tossed about the aircraft, and the airspeed is affected in excess of 25 knots.

- *Extreme turbulence.* Extreme turbulence is relatively rare. The aircraft will be tossed about and control is practically impossible. Rapid fluctuation of the airspeed occurs in excess of 25 knots. Such turbulence may cause structural damage to aircraft.

10-8. Flight Techniques

In planning a flight into existing or expected thunderstorm areas, the aviator should try to determine whether the thunderstorms will be sufficiently scattered to permit circumnavigation or will be sufficiently numerous to require flight through them. Radar weather reports are helpful in locating thunderstorm areas and in determining how numerous the storms are. The aviator should also check SIGMETS, PIREPS, AIRMET's, and SCAN reports (chap 11) for the latest information available on storm areas along his route. In consulting with the meteorologist, the aviator should learn the height of the freezing level as an aid in selecting the proper flight altitude to avoid maximum lightning and icing areas. When a radar scope is available at the weather station, the aviator should check the radar picture to correlate the location and intensity of the storms in the immediate area. The aviator must then decide if it is possible to circumnavigate the storms or to avoid them by over-the-top or under-the-base flight. If all routes to avoid the storm are closed, he must decide if the mission is sufficiently important to warrant penetrating the storm clouds.

a. Avoiding the Storm.

(1) *Circumnavigation.* Circumnavigation presents no special flight problems. When circumnavigation is possible (as in isolated airmass storms), the aviator alters his course to go around the storm. Since most thunderstorms are less than 25 miles across, a slight detour adds negligible time and distance to the flight route. With a line of thunderstorms, circumnavigation by flying through "thin spots" between storm centers may be possible. Since another thunderstorm may lie at the end of the "thin spot," however, the aviator should contact METRO on available frequencies for guidance in selecting the proper "thin spots" for penetration.

(2) *Over-the-top flight.* Over-the-top flight is normally impossible in current Army aircraft because of altitude and oxygen limitations.

(3) *Flying under the base.* When circumnavigation is impossible, flight may be possible under the base of the storm if it lies over the sea or over flat open country. Flights should never be conducted under the storm in mountainous areas unless there is

a definite ceiling with good visibility underneath. Ceilings may drop rapidly when precipitation begins. Storms in mountains customarily have their bases below and often around peaks. When flying underneath storms, choose an altitude one-third of the distance from the ground to the base of the clouds and circumnavigate the heavy rain shower areas. Since the bases of storms usually average about 3,000 feet (except in mountainous regions), this altitude will provide adequate terrain clearance and avoid the worst turbulence of the storm region.

b. Penetration of Storm. When it is not possible to avoid the storm, the aviator must decide if the urgency of his mission requires penetration. Since directional changes place additional stress on the aircraft structure, the aviator should not attempt to turn back once the penetration is begun. The lower in the storm the penetration, the less the chance of encountering severe turbulence, hail, and structural icing; also, the less the chance of being struck by lightning. Adequate terrain clearance should be considered in the selection of a penetration level. The minimum penetration altitude should be 4,000 feet above the highest terrain in the area. The pressure altimeter in the aircraft indicates the approximate altitude above sea level. A rule of thumb for the selection of a penetration level is—minimum 4,000 feet of terrain clearance and indicated free air temperature of at least +5° centigrade. It should be remembered that free air temperature gages are often 1° to 3° in error. Most aircraft operator's manuals recommend a penetration altitude of 6,000 feet above the terrain. Thunderstorm Project results show the best penetration altitude is 4,000 feet to 6,000 feet above the terrain.

(1) *Preparing for penetration.* Since both direction and attitude of the flight are to be maintained by reference to the gyro instruments, they should be checked carefully before entering the storm. To guard against temporary blindness from bright flashes of lightning, dark glasses should be worn and the cockpit lights should be turned on full. The aviator should turn off all radio equipment rendered useless by static, and use VHF or UHF frequencies which are not significantly affected by static. (If applicable, the carburetor mixture should be set FULL RICH.)

(2) *Speed of flight.* The speed an aircraft is flying when it strikes an updraft or downdraft deter-

mines the shock it will experience. The operator's manual for the particular aircraft gives the correct range of speed for penetration. If hail is encountered, the aviator should slow the aircraft to the minimum speed recommended for flights in severe turbulence.

(3) *Icing.* Since ice formation in the pitot tube and carburetor is probable, heat should be applied to both.

c. Flight Through Thunderstorm.

Warning: Because of the potential hazards of thunderstorm flying, unnecessary penetration of thunderstorms must be avoided. The experience of airline pilots and others operating large aircraft has shown that it is possible to fly into thunderstorms if crews are experienced in thunderstorm flying, if suitable aircraft are used, and if the proper flight techniques are used. Limited studies and experience have revealed techniques for thunderstorm flying, but not all aviators experienced in thunderstorm flying are in full agreement as to the best techniques. The rules that are generally accepted by experienced aviators and which appear to be substantiated by the limited studies that have been completed are—

(1) Accomplish thunderstorm penetration at 4,000 to 6,000 feet above the terrain since this is the safest altitude in most storms.

(2) Fly at the airspeed or power setting recommended in the operator's manual.

(3) Establish airspeed and power settings before entering the storm.

(4) Fly at constant attitude and power setting as far as possible. Erratic readings of airspeed result from vertical drafts past the pitot tube and the clogging effects of rain and ice.

(5) Avoid all unnecessary maneuvering—to prevent adding maneuver loads to the loads already being imposed by the turbulence.

(6) Avoid use of an autopilot (if applicable). The autopilot, a constant altitude device, will pitch the aircraft downward to compensate for an updraft and upward for a downdraft. In updrafts excessive airspeeds may be built up, and in downdrafts the airspeed may approach the stalling speed.

(7) Hold a reasonably constant heading through the storm. Wandering will only prolong the flight and increase the dangers.

PART TWO WEATHER FACILITIES AND THEIR APPLICATION

CHAPTER 11 WEATHER SYSTEMS

Section I. GENERAL

11-1. General

To provide aviation with current information on both observed and forecast weather conditions for use in pre-flight, en route, and terminal operation anywhere in this country and for most parts of the world is a tremendous undertaking. It requires the cooperation of several military and civil governmental agencies, private individuals and organizations, and finally the user himself through the solicitation and usage of Pilot Reports (PIREP). In many cases, the basic objective of a single organization may be to collect, analyze, and use weather data for their own unique requirements. One example would be the military and its requirement for information used in ballistics or rocketry. Another example is the Office of Climatology and its need for use in determining average rainfall, temperature, and other factors applicable to agriculture and commerce. To best serve all interests, agencies exchange information extensively. Specific jobs are handled by one agency for use by all to eliminate duplication of effort (fig 11-1). Paragraphs 11-2 through 11-5 will encompass the major operations of observing, analyzing and forecasting, distribution of data, and the different methods of presenting the weather information to the user. In paragraphs 11-6 through 11-20, and in subsequent chapters of this manual, the actual coded reports, forecasts, and weather maps will be discussed.

11-2. Sources of Weather Data

a. General. The backbone of any weather forecasting service is the mass of weather data that is collected regularly from the thousands of observing stations. These observing stations are usually staffed by the same people that will have a need for this information from other stations. Consequently, the collection and distribution of much of this data is done simultaneously through computer controlled teletype systems (para 11-8).

b. Surface Observations. Surface observations are made by the National Weather Service airport stations, the military weather services, Federal Avia-

tion Agency (FAA) specialists at selected flight service stations and tower facilities, commercial airline and airport operators, ships at sea, and automatic observing stations. Surface observations normally include the following: sky cover, ceiling, visibility, precipitation, obstructions to vision, sea level pressure, temperature, dew point temperature, wind, and altimeter setting.

c. Upper Air Soundings. Observations of conditions aloft furnish information on temperature, humidity, pressure, and winds. Approximately 80 stations make upper air observations. They are obtained by sending aloft a balloon with miniature weather observing equipment tied to a small radio transmitter called radiosonde (fig 11-2). Tracking the balloon by radar provides wind information. These devices called RAWINSONDES provide the basic data for construction of constant pressure and adiabatic charts.

Note. When a balloon without the transmitter/observation equipment is tracked visually, it is called a pilot-balloon observation (PIBAL). A balloon with only a reflector for radar tracking is called a radar wind sounding device (RAWIN).

d. Reconnaissance Flights. Military reconnaissance flights are another source of weather data. These flights are often set up to cover specific areas which are inaccessible by land and water. These flights are conducted by reconnaissance squadrons that fly into hurricanes and typhoons, fix the storms position, and gather data.

e. Pilot Reports (PIREP). Reports from aircraft operations throughout the world also make a large contribution to the weather forecasting service since they can report the weather conditions in areas not otherwise accessible, and at altitudes where conditions could not be determined by surface observation or upper air soundings.

f. Satellite Observations. One of the greatest developments in the observation of weather is the use of meteorological earth satellites. This program began

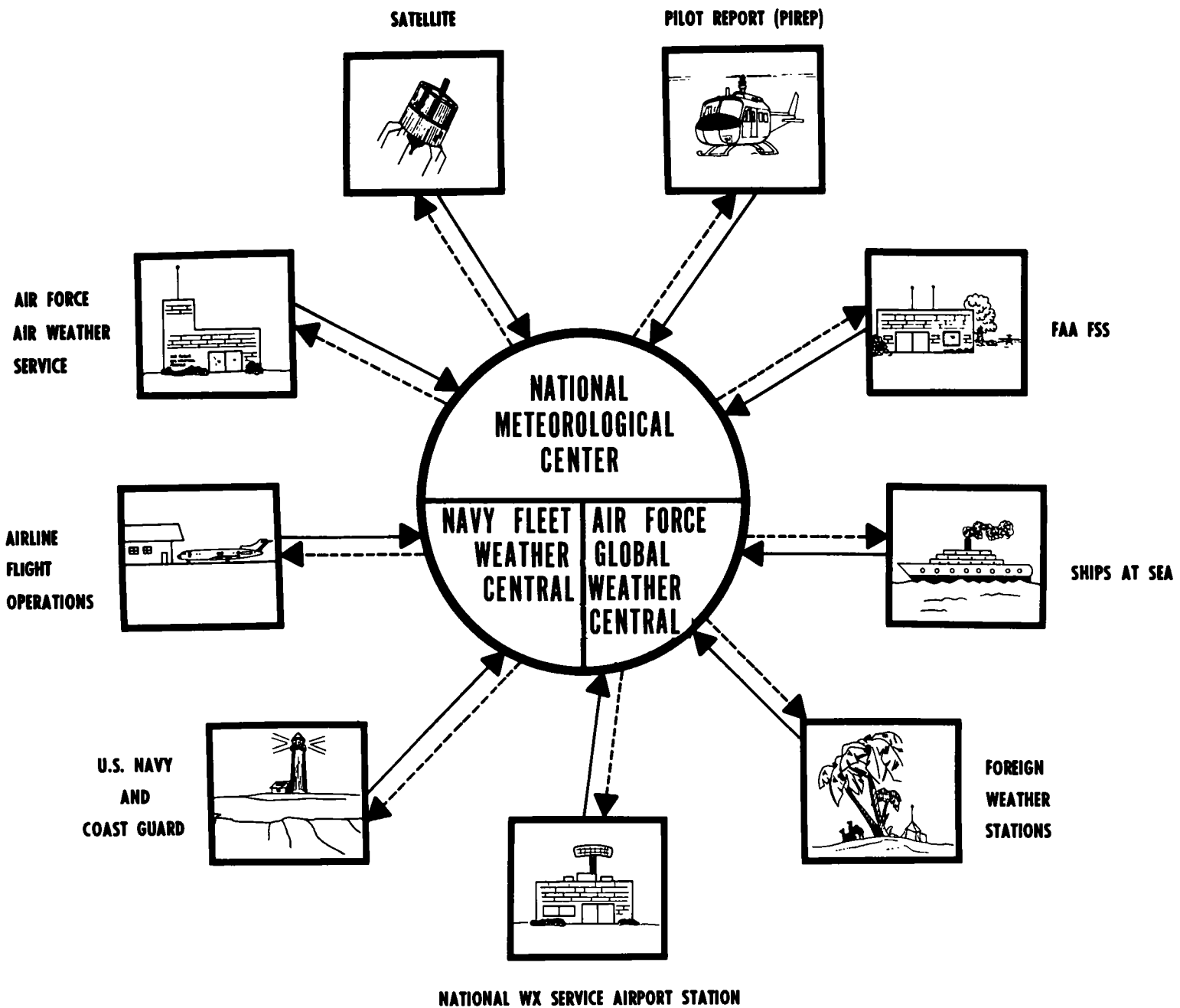


Figure 11-1. Sharing of weather data and analysis.

in 1960 and has become an important input to the analysis and forecasting of weather. Satellites provide daily global weather photographs of major weather systems such as fronts, storm centers, tropical flows, and hurricanes. This information combined

with other weather data (fig 11-3) provides the forecaster with needed information to determine the direction of circulation, wind speeds, path of the jet stream, as well as being able to identify squall lines and cloud bands associated with frontal systems.

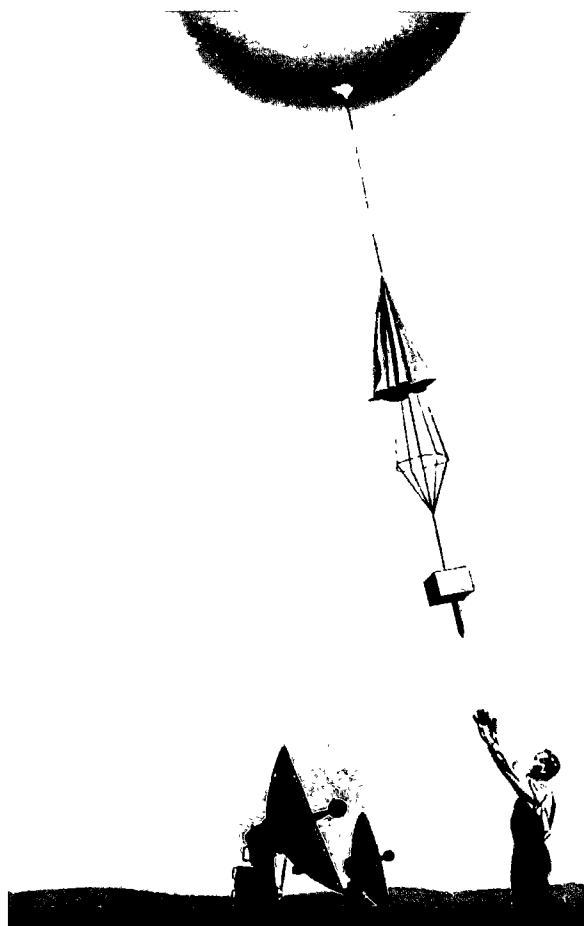


Figure 11-2. Radiosonde equipment being released.

11-3. Analyzing and Forecasting

The collection and distribution of weather observations in itself is quite useful for aviation but is very limited. This information must be combined into a more meaningful form if a total weather picture, including expected changes, is to be made available. The task of analyzing and forecasting weather begins at a national level and is then further refined in regional and local weather facilities.

a. National.

(1) *National Meteorological Center (NMC).* The National Meteorological Center of the National Weather Service located near Washington, D.C. provides the basic analysis of all observed conditions to prepare surface and upper level charts and forecasts for use by the entire aviation community (fig 11-4). The talents of many meteorologists and support personnel at the National Meteorological Center are used to convert the mass of incoming weather data to map-like displays and prognosis which are then transmitted to both civil and military weather facilities by means of facsimile machine and teletype.

Note. Facsimile machines are similar to those used by newspaper and wire services for transmitting photographs.

(2) *National Severe Storms Forecasting Center.* The National Severe Storms Forecasting Center is located in Kansas City, Missouri and monitors conditions in the North American atmosphere using surface data, radar summaries, satellite photographs, upper air soundings, and pilot reports to determine areas most likely to experience severe thunderstorms and tornadoes. This facility prepares severe thunderstorm and tornado watch bulletins and warnings which are then distributed through television and radio to the affected areas.

(3) *National Hurricane Center.* The National Hurricane Center (NHC) at Miami, Florida, has the responsibility for the hurricane warning program in the Atlantic, Caribbean, and Gulf of Mexico. Additional centers at San Francisco and Honolulu provide coverage for the eastern and central Pacific. These centers use data from reconnaissance aircraft, satellite photos, radar, and reports from ships at sea to analyze, track, and predict intensity and direction of movement of hurricanes and typhoons.

(4) *High Altitude Forecast Office.* A special section of the National Meteorological Center is the High Altitude Forecast Office. This facility produces operational forecasts primarily for airlines and military aircraft operating at those altitudes. Additionally, they exchange information with other high altitude forecast units around the world to provide highly specialized forecasts for wind, temperature, significant en route and terminal weather for international flights.

(5) *National Environmental Satellite Service.* The National Environmental Satellite Service is located at the World Weather Building near Washington, D.C. Here the basic weather satellite data is received and used in conjunction with other weather information by meteorologists in their task of forecasting weather. Two types of satellite operations are used to provide this coverage.

(a) *Polar orbital satellites.* The first is a relatively low altitude polar orbiting system where the radiometers scan successive segments of the earth's surface with each orbit. The use of infrared equipment provides for collection of information on the dark side of the earth. The early systems required plotting of cloud photos into a mosaic to provide proper orientation. Today, computers make possible a display of cloud photos on polar and equatorial projection maps with geographic grid lines and outlines of land masses included. The polar orbiting satellite system does have limitations. It requires 12 hours for the earth to rotate until a storm system can be viewed a second time. This allows much of our more serious weather to form, do its damage, and decay before a polar orbit could get a second look. What is needed is a weather satellite so positioned in orbit that it would rotate at the same rate as the earth and maintain its position

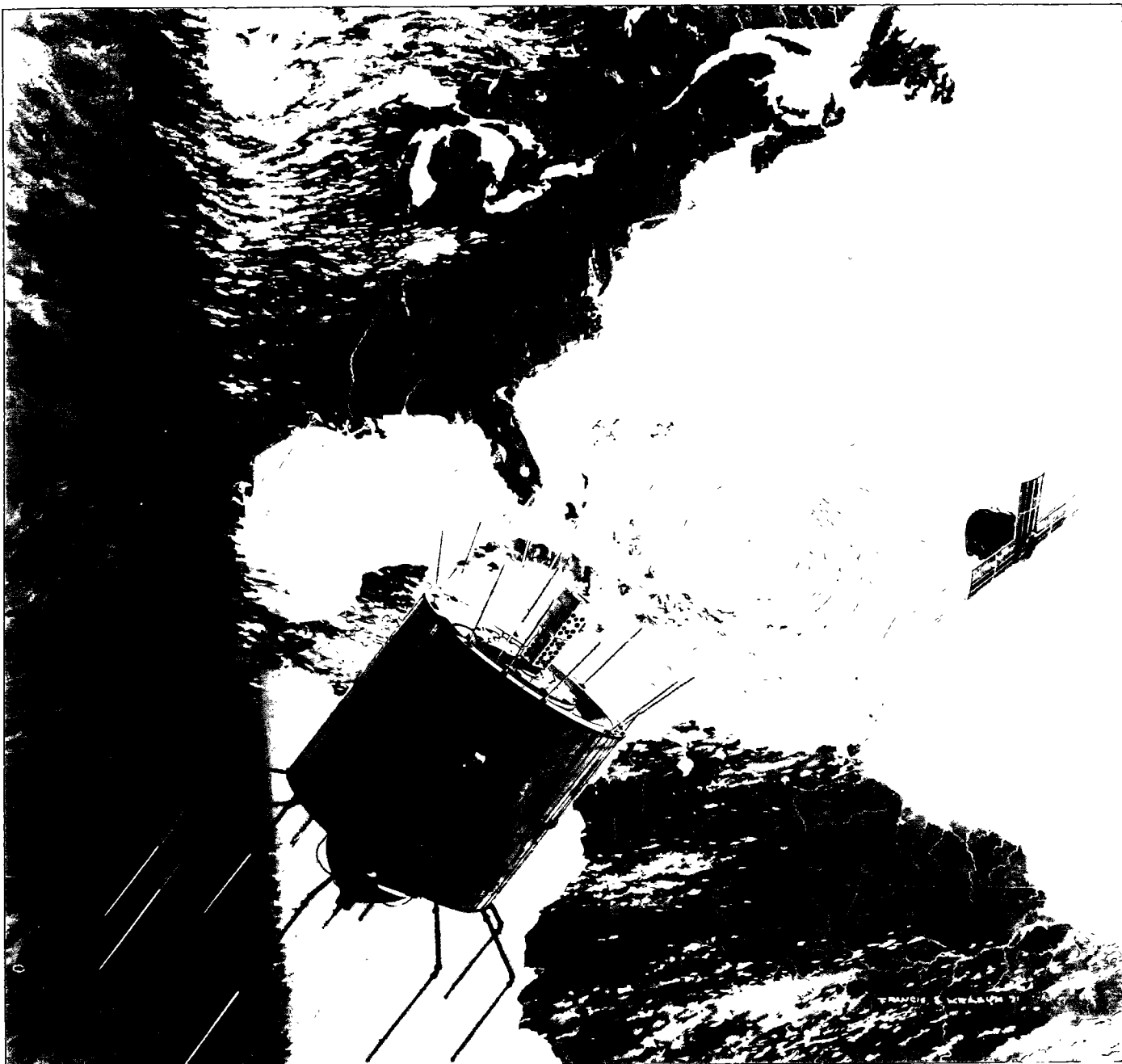


Figure 11-3. Weather watch—satellite, aircraft, and coastal radar.

over the same point on earth.

(b) *Earth synchronous satellites.* There are satellites now in orbit that are earth synchronous (called geosynchronous or geostationary) at selected locations which provide continuous viewing of cloud cover and serve as a data-relay between weather centers and outpost sensor platforms. Since the viewing from these platforms is almost continuous, motion picture loops of the cloud systems movement can be assembled for measuring wind flow, storm life cycles, air mass migration, and even detection of thunderstorm development with a possibility of early detection of severe local storms and tornadoes. This

system is a major portion of the early detection, tracking, and forecasting of hurricane and typhoon warnings.

b. *Weather Service Forecast Offices (WSFO).* There are 52 Weather Service Forecast Offices serving the United States (fig 11-4). These facilities are responsible for warnings and forecasts for statewide areas and assigned zones. With the use of national weather data described above, these offices can prepare a more detailed forecast for their zone or area. These offices prepare and distribute aviation terminal forecasts three times a day for major airports in the 50 states and the Caribbean. They also prepare forecasts for

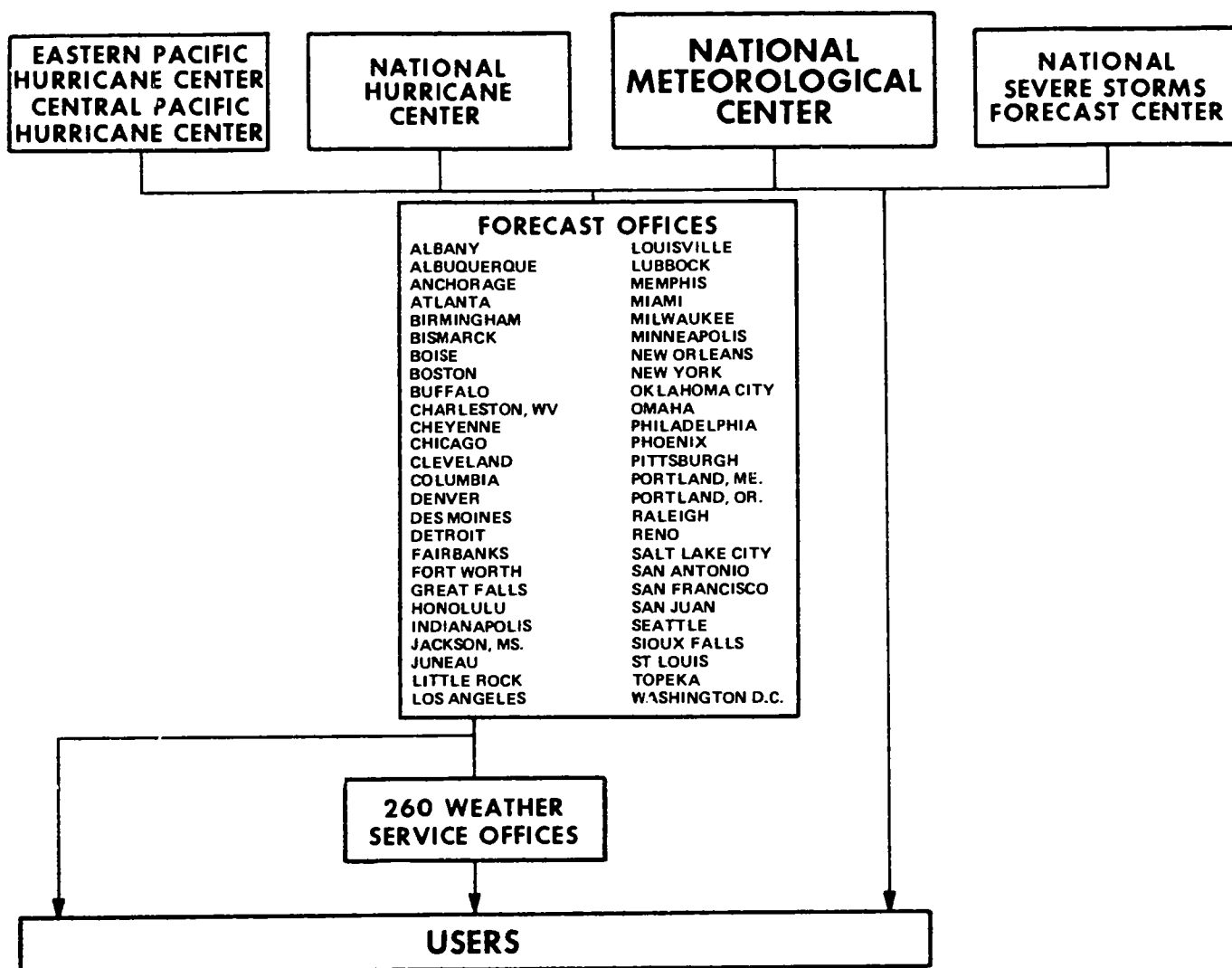


Figure 11-4. Structure of forecast organization.

the conterminous US used in transcribed weather broadcasts (TWEB), and Pilots Automatic Telephone Weather Answering Service (PATWAS) for use in briefings (para 11-5c). Twelve WSFO's also prepare Area Forecasts (FA) for aviation covering designated geographical areas and issue in-flight advisories to warn pilots of potentially hazardous weather (see chapter 16 for detailed coverage of Terminal and Area Forecasts).

c. Weather Service Offices (WSO). Weather Service Offices represent the third echelon of the system. These offices prepare local forecasts from the zone forecasts to better define the local conditions for public use. These offices are normally located at airports (formerly called Weather Bureau Airport Stations) and provide weather briefings for pilots departing those fields (para 11-5).

d. Military Weather Services. The military weather facilities use data from all the national weather agencies described in paragraph 11-3. They also have

weather centrals similar to NMC and a second and third echelon function to the total forecast organization similar to the WSFO's and WSO's.

(1) *USAF Air Weather Service.* The Air Weather Service provides forecast and briefing services to both Air Force and Army installations and normally has a weather station at each Air Force base and many US Army airfield locations. A forecaster is normally on duty during operational hours to provide aircrews with person-to-person weather briefings for each mission. In support of the Army, the AWS has specialized weather teams to live, train, and deploy with selected units, providing them with environmental services tailored to their specific needs.

(a) *USAF Global Weather Central (AFGWC).* The AFGWC is the primary Air Weather Service centralized facility for production of atmospheric and space weather products to support AF and Army operations. This facility is equipped and staffed to analyze weather data and prepare forecasts on a

worldwide basis in support of global operations. The AFGWC is designed with a complementary system mix of modern computers and skilled personnel in order to build, maintain, and apply the meteorological data base to specific operational requirements.

(b) *USAF Tactical Forecast Units (TFU)*. These units provide tailored support to a specified geographical area or designated command. The primary meteorological support for these units will originate from AFGWC. The TFU is designed to provide quick response contingency support.

(c) *USAF Weather Support Unit (WSU)*. These units essentially function as an around-the-clock Staff Weather Office. They are small groups of skilled personnel, collocated with major operating units; configured to provide direct atmospheric and space weather support information/assistance to decisionmaking processes for command and control of military forces.

(d) *Base/Post Weather Station*. Units collocated in a specific USAF or USA airfield that provide locally tailored observing, forecasting, and briefing support.

(e) *Organic Weather Team (OWT)*. Provides locally tailored observing, forecasting, and briefing support in a field environment to tactical Army corps, divisions, and brigades.

(2) *US Navy Weather*. The Navy Weather Service functions in a similar manner to the Air Weather Service. It has a fleet weather central to provide detailed meteorological and related services to Department of Navy and oceanographic forecasts to armed forces of the Department of Defense.

(a) *Fleet Weather Facilities*. This level of the Navy Weather Service provides a local service in support of the fleet weather centrals and parallels the forecast centers in the Air Weather Service. Both activities analyze and prepare forecasts for their specific requirements and make widespread use of data supplied by the National Meteorological Center (NMC).

(b) *Navy Weather Service Facilities*. This represents the lower level of the Navy Weather Service and is comparable to the civil Weather Service Office (WSO) and the Air Force Air Weather Service facilities at the airfield locations. These offices would provide the normal display of facsimile charts and teletype data, and offer full person-to-person telephone or television pilot briefings to Navy and transient aviators.

11-4. Distribution

Weather information is extremely perishable due to its changeable nature. It is important to have a means for rapidly collecting and distributing the observations and weather forecasts. This is accomplished by

use of long line teletype circuits and facsimile machine networks (fig 11-5). Although both teletype and facsimile machine transmission speeds have been greatly increased in recent years, it is still necessary to use a code format to facilitate the communication of weather data. The code used is standardized for use by both civil and military facilities in the United States. A different but similar code is in use by other countries of the world (para 11-20).

a. *Teletype*. The primary United States civil government system used for distribution of aviation weather information is service A, C, and O operated by the Federal Aviation Agency (FAA).

(1) *Service "A."* Service A is the most important circuit to aviation users. It is used to collect and distribute hourly surface aviation observations and to disseminate products of aviation weather service and

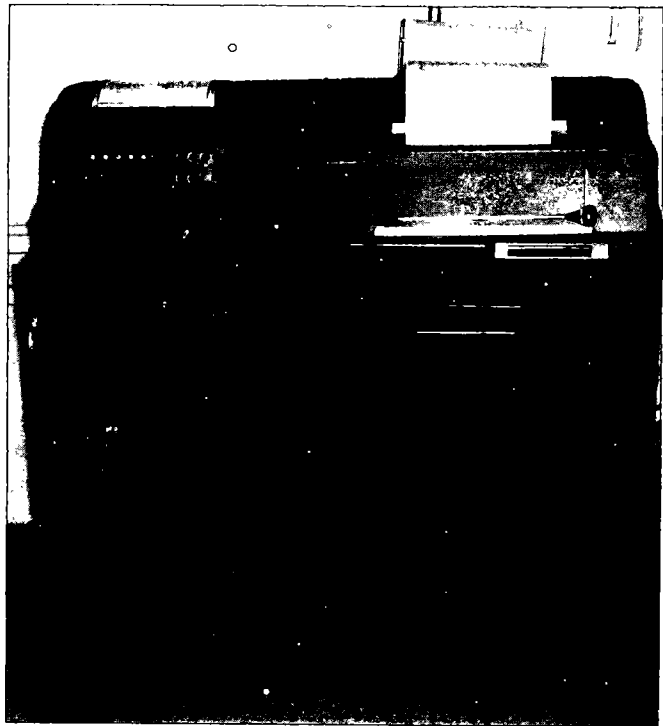


Figure 11-5. Long line teletype and facsimile machines.

tional data. This network serves approximately 260 weather service offices, 470 military and other government units, and 370 extension service (nongovernmental) users. Approximately 130 charts measuring 12 x 18 are distributed each day. With the exception of radar summary charts prepared by the National Severe Storms Forecasting Center and the digitized mosaics from the National Environmental Satellite Service, all material originates at the National Meteorological Center at Suitland, Maryland.

(2) *National and Aviation Meteorological Facsimile Network (NAMFAX)*. This is a high-speed network transmitting the combined graphic material of the old AMFAX and the NAFAX networks. NAMFAX provides a program in which a limited number of main meteorological offices prepare area forecasts of winds, temperature, and significant weather primarily for international flights above 20,000 feet.

(3) *Strategic Facsimile Network (STRATFAX)*. This is the basic strategic facsimile network (AF-109) used to distribute to military units a comprehensive set of charts depicting analysis, prognosis and winds for selected worldwide areas. AFGWC produces the products on this circuit for dissemination.

(4) *PACFAX/EURFAX*. This is the basic facsimile circuit used to distribute analysis, prognosis, and other weather data to military units in overseas areas. The data on these charts are tailored for use in the European (EURFAX) and Pacific (PACFAX) area. AFGWC is the production facility for these charts.

11-5. Presenting the Weather

a. General. The methods used to present the weather data to the user will vary. They range from a complete thorough briefing by a military or civil forecaster with the aid of total teletype and facsimile machine coverage to a self-briefing accomplished by reference to a limited amount of teletype and other data at an unmanned location.

b. In-Person Briefing. At most large military airfields, a weather office is available for preflight briefing (fig 11-7). Many civil fields have either a National Weather Service (NWS) or FAA Flight Service Station office to provide a weather briefing (fig 11-8).

Note. National Weather Services Offices will normally have a forecaster on duty. FAA Flight Service Station personnel are certified by NWS as weather briefers.

In most of these cases teletype and facsimile machines furnish the necessary weather data to support this service. The data available will vary slightly at different facilities but will normally include the items shown in figure 11-9. The display of charts and tele-

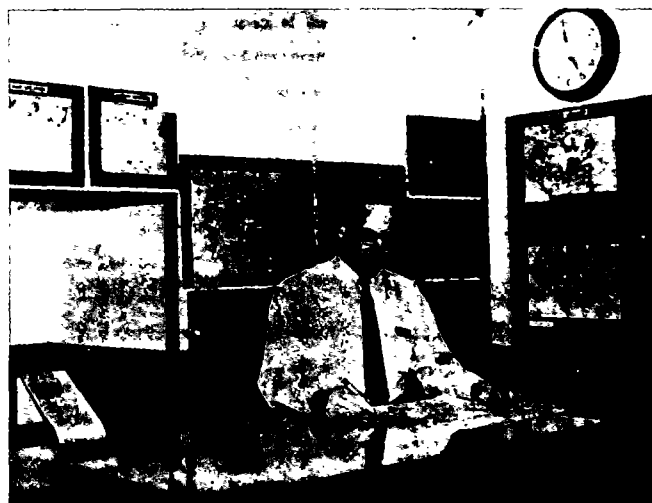


Figure 11-7. Typical weather briefing room.

type reports will also vary somewhat but will be similar to that shown in figure 11-7.

(1) *Radar usage.* A relatively new procedure at many military and civil briefing offices and FAA Flight Service Stations is the use of a weather radar scope to enhance the briefing. Many of these at the smaller facilities will be repeater scopes from larger weather installations.

(2) *Television.* Closed circuit television has been used extensively by the military for briefing pilots at outlying fields. This system is also used by the civil facilities but to a lesser degree. This method of briefing is second only to a face-to-face briefing since the pilot sees the charts on which the forecasts are made along with the briefer comments.

c. Recorded Weather Briefing. There are two systems used to provide weather briefings (fig 11-10).

(1) *Pilots Automatic Telephone Weather Answering Service (PATWAS)*. At some locations, the number of pilots requiring flight weather briefings are too numerous for person-to-person briefings. Therefore, recorded weather briefings are available at several locations providing expected weather conditions up to 12 hours in advance. PATWAS locations are listed in the Airman's Information Manual, Part II, and are normally publicized in the flight planning rooms.

Note. In some cases the PATWAS telephone number will connect the caller to the TWEB described below.

(2) *Transcribed Weather Broadcasts (TWEB)*. Equipment is provided at selected locations for transcribed meteorological and notice-to-airman data to be continuously broadcast over low frequency navigational aids and VOR's. Route forecasts are normally issued three times a day with the first two valid for 12 hours and the third valid for 18 hours. Facilities

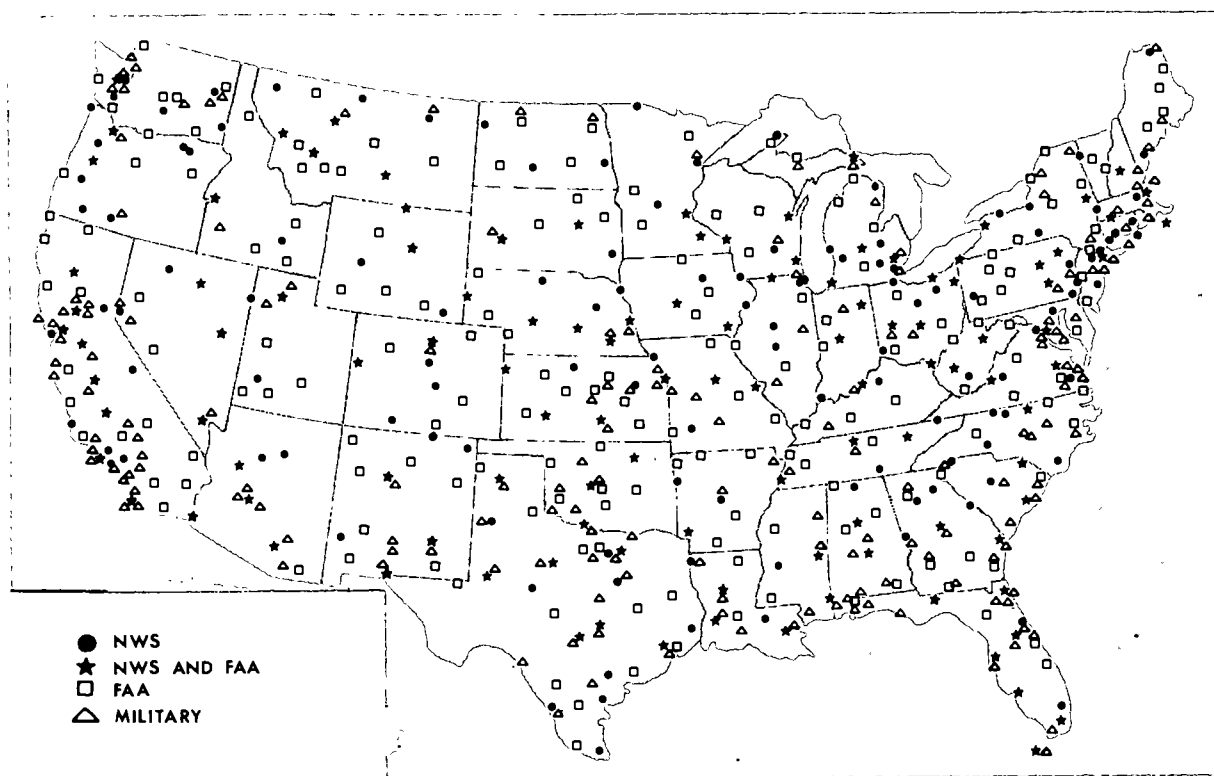


Figure 11-8. Weather briefing offices (person-to-person).

HOURLY AND SPECIAL WEATHER REPORTS
PILOT REPORTS ON ICING, TURBULENCE, CLOUD TOPS, ETC.
TERMINAL AND AREA FORECASTS
RADAR REPORTS AND SUMMARY CHARTS
WINDS ALOFT DATA
SURFACE ANALYSIS AND WEATHER DEPICTION CHARTS

Figure 11-9. Information available at typical weather briefing facilities.

offering this service can be found in the navigational publications.

d. Person-to-Person Telephone Briefings.

(1) *Military.* Aviators can call a nearby USAF/USN weather briefing facility when a weather service office is not available. These facilities can provide a full weather briefing for the flight. (A listing of USAF/USN weather briefing facilities is available in the FLIP supplement and includes AUTOVON and commercial telephone numbers.) The USAF Air Weather Service Regional Briefing Service (RBS)

operation consists of regional 24 hour weather stations supporting nearby (satellite) stations during periods of closure. A standardized briefing display board is maintained at both the RBS and the satellite station. A pilot preparing his flight plan studies the display board and then calls the RBS by AUTOVON to receive his flight plan briefing. (See chapter 17 for details of RBS usage during flight planning.)

(2) *Civil airports.* Aviators departing civil facilities which do not have weather service available may contact National Weather Service (NWS), FAA Flight Service Stations, or combined station towers (CST) by telephone. Telephone numbers of these facilities may be found in Airman's Information Manual, Part II. Most of these numbers are restricted for aviation use only and in many cases long distance calls can be made through a toll free leased line service at the price of a local call.

Note. Army aviators should decide which method would be least expensive to satisfy their needs. Long distance (collect) commercial calls can be made when considered necessary.

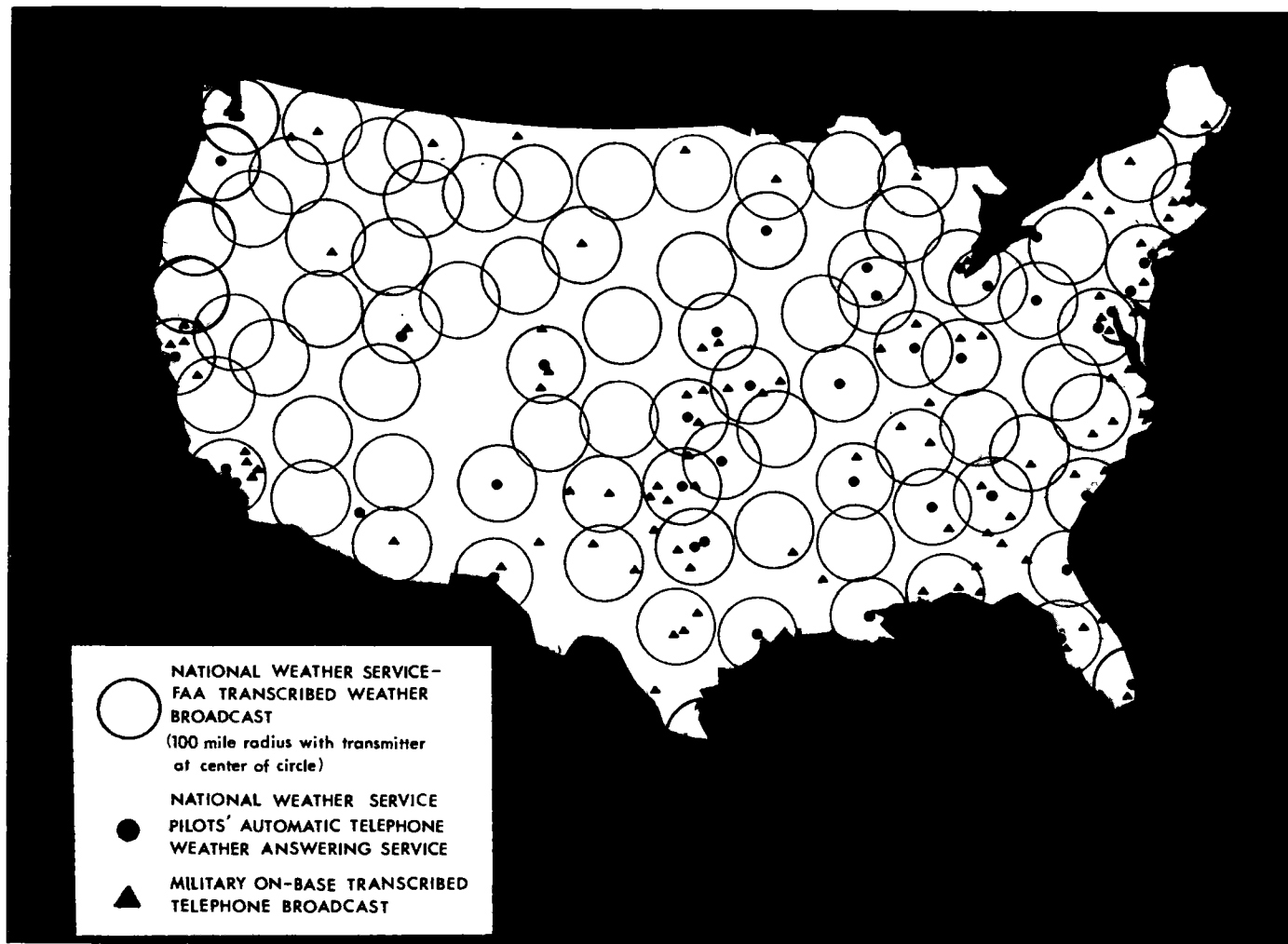


Figure 11-10. Ground briefing facilities (transcribed).

Section II. TELETYPE SEQUENCE REPORTS

11-6. General

Teletype circuits provide the most rapid means of collecting and relaying existing weather condition data over a wide area. They are also useful for checking weather trends, for amending and verifying forecasts, and for supplementing other infrequently reported data. The frequency of teletype sequence reports makes them valuable tools for the aviator and the forecaster.

Note. The data furnished, the format used, and the times of transmission of all teletype and facsimile machine weather information are subject to change to make use of new developments and to best serve the requirements of the aviation community. The material included in this section describes the methods used at time of publication and reflects the normal in most cases. The number of reports or charts prepared and distributed will vary as appropriate to both user needs and the severity of the weather phenomena.

11-7. Reporting Agencies

When an aviator is planning a flight, weather reports normally will be available from National Weather Service stations, Federal Aviation Agency (FAA) Flight Service stations, and all military installations that have a weather reporting source. The National Weather Service stations and the FAA Flight Service stations are responsible for making weather observations and transmitting these reports from civilian facilities. Supplementary weather reports are made at many airports by airline or airport employees and other cooperators. Weather observations at these points are filed with stations which can give them the required distribution. The Air Weather Service (Air Force) is responsible for weather observations taken and transmitted by Air Force and Army installations. The Naval Weather Service satisfies the weather requirements at naval air stations. To obtain complete weather coverage, the various weather agencies

in the CONUS always exchange their reports and, during peacetime, this exchange of weather data is international in scope.

11-8. Teletype Circuits for Sequence Reports

a. General. Teletype aviation weather sequences are transmitted from hundreds of observation points and relayed to other weather stations over a network of numbered teletype circuits to provide weather information to both civil and military facilities. The Modernized Weather Teletypewriter Communications System (MWTCS) consolidates the circuit control and relay functions of the teletype service into a single Weather Message Switching Center (WMSC) at Kansas City, Missouri (NKA) ((A), fig 11-11). These functions are performed automatically by a group of electronic computers which are combined to operate as a real-time, store-and-forward communications switch. Computer-to-computer links provide for the

exchange of data between the WMSC and the National Meteorological Center at Suitland, Maryland, and between the WMSC and the USAF Automated Weather Network (KAWN) at Carswell AFB, Texas. The network used to serve the FAA and national Weather Service facilities in the United States consists of 40 circuit areas with approximately 12 stations in each ((A), fig 11-11). Eight circuit areas within the United States are used to cover the military facilities ((B), fig 11-11). The distribution pattern of the data relayed to each circuit is the result of extensive coordination with each user and is designed to meet his requirements as closely as possible. The teletypewriters operate at approximately 100 words per minute, and only a few minutes are required to collect all reports from any one circuit. When a station is polled for transmission of its report, all stations programmed to receive it will do so simultaneously.

b. Distribution Patterns. The FAA and National

(A) FEDERAL AVIATION ADMINISTRATION SERVICE A MODERNIZED WEATHER TELETYPEWRITER COMMUNICATIONS SYSTEM

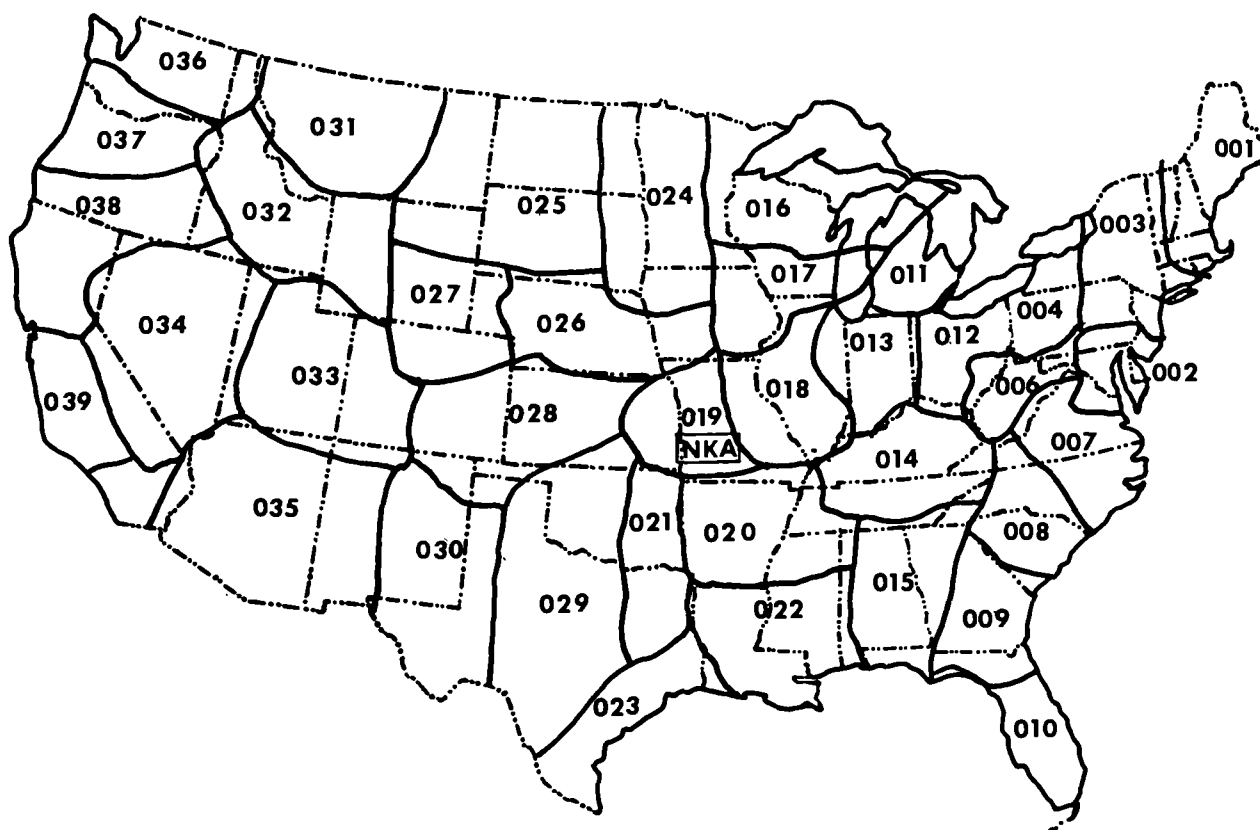


Figure 11-11. Military and civilian teletype circuit areas.

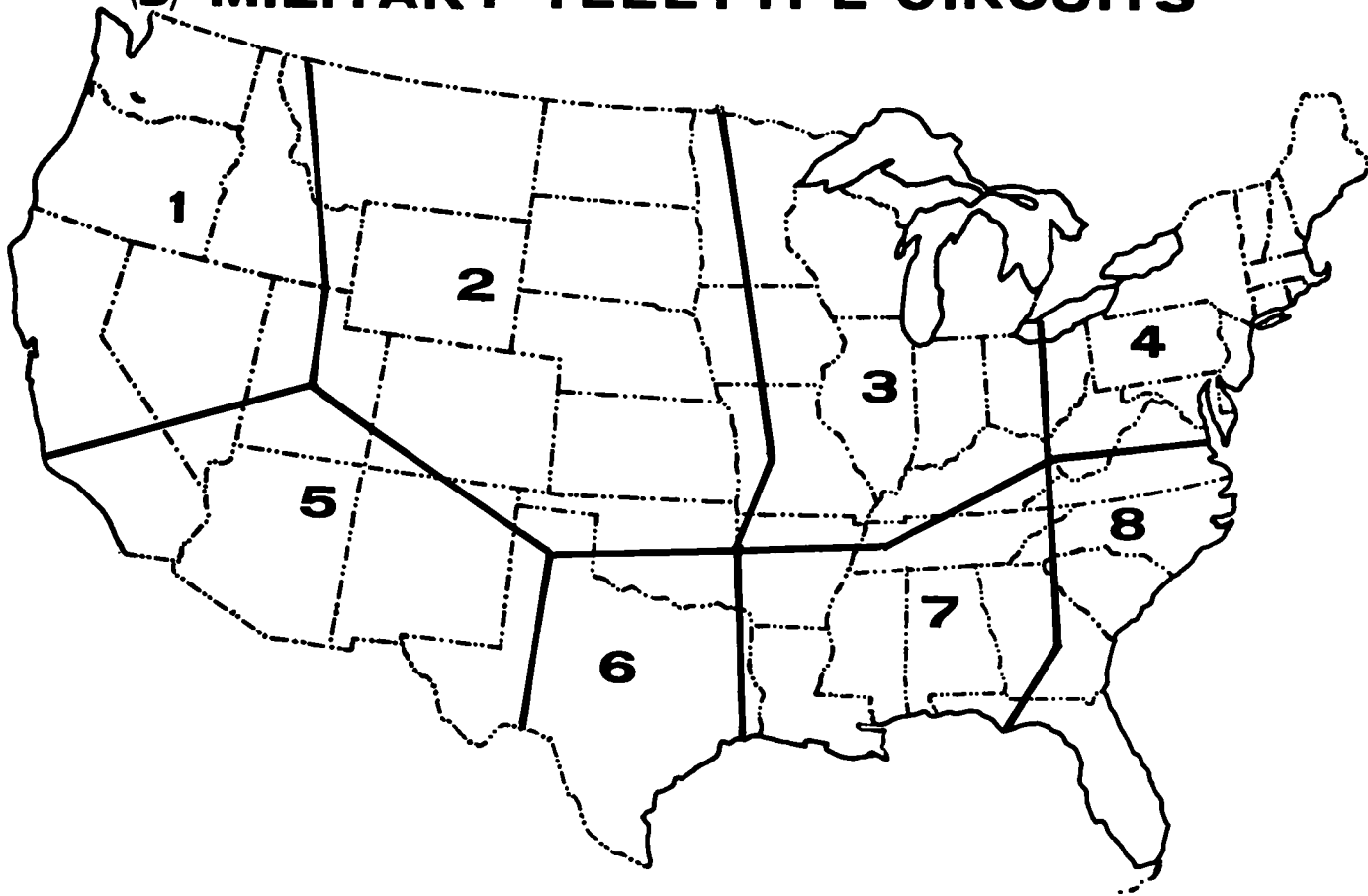
(B) MILITARY TELETYPE CIRCUITS

Figure 11-11—Continued

Weather Service use a system of distribution wherein each station in a given circuit will receive hourly sequence and other reports from *every* station in its own area ((A), fig 11-11), plus reports from selected stations from other circuit areas. As an example, each station in circuit 15 (fig 11-12) receives the basic group of teletype Service A (SA) reports each hour. It will also receive groups of selected stations (fig 11-13) outside the basic circuit area listed by state. In addition, most stations are programmed to receive one other group for their nearby military stations. This system provides adequate coverage for each station by making available a greater number of reports for stations near the basic area with a sampling of major facilities in the distant regions. To completely round out the teletype coverage, a *request/reply* circuit provides for specialized callup service for Flight Service stations and Weather Service offices. With this circuit, any station can request and quickly receive weather coverage for any station not available in the standard distribution. The military distribution parallels that of the civil facilities. Each military sta-

tion will receive full coverage of the circuit in which it is located (circuit 4, fig 11-14). To complete their needs, nearby circuits that are desired will also be received, as well as selected civil facilities in and outside the area. The selected civil facilities teletype reports are set up in a consecutively numbered system. The military facilities also have a *request/reply* circuit available to provide callup service for needed weather information at any point not covered in their distribution of weather reports.

c. Circuit Headings. The circuit headings enable the aviator to locate the reports needed for a particular flight.

(1) *SA15 101300 (Fig 11-12).* The SA is a symbol used for hourly sequence reports of surface observations for aviation. The 15 is the circuit number identifying the geographical area ((A), fig 11-11) from which the subsequent reports were transmitted. The 101300 is the date-time group. The first two digits (10) indicate the day of the month, and the next four digits (1300) indicates the time on the 24-hour clock in Greenwich Mean Time (Zulu).

MGM MONTGOMERY, AL CEW CRESTVIEW, FL PNS PENSACOLA, FL TCL TUSCALOOSA, AL BHM BIRMINGHAM, AL MSL MUSCLE SHOALS, AL ANB ANNISTON, AL RMG ROME, GA ATL ATLANTA, GA FTY ATLANTA, GA FULTON COUNTY DHN DOTHAN, AL	SA15 101300 MGM 10SCT E25BKN 950VC 7 134/78/75/2205/994 RB40E51 CEW 12SCT E25BKN 1000VC 10 147/80/72/2408/997/RE30 PNS 8SCT M12BKN 500VC 7 153/81/71/2510G17/999/DRK S TCL E18BKN 5K 135/81/72/3610/995 BHM M17BKN 4HK 135/81/72/3207/995-BHM7/10 MSL 35SCT 300SCT 10 147/84/70/0109/998-MSL8/2 ANB 12SCT E250VC 3H 127/78/70/2908/993-ANB8/9 RMG E 5 BKN 30 OVC 1 TRW+ -13/73/71/11--/994/RVNOVVV/MTB16 RB23 OCNL THDR WNW MOVG ENE ATL E12BKN 800VC 10 127/76/72/2406/994/RE10-ATL7/4 8/2 8/3 FTY E25BKN 1500VC 5H 78/70/2805/993/THN SPOTS 10VC DHN E20BKN 80BKN 2500VC 10 142/79/71/1914G20/996-DHN7/9 -NOSUM101302 -BHM 7/10 BHM 5-23 CLSD 0530-1200 MON-FRI THRU 11/15 -MSL 8/2 LRT NDB OTS -ANB 8/9 GAD 6-24 CLSD 2KDAY 1200-SS EXCP PPO -ATL 7/4 CTJ NDB OTS -ATL 8/2 ATL ILS 8 OTS TIL 9/18 -ATL 8/3 ATL ALS 8 OTS -DHN 7/9 TOI 1-19 CLSD
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Figure 11-12. National Weather Service and FAA hourly sequence (basic circuit).

Note. The Federal Aviation Administration utilizes Greenwich Mean Time (GMT or "Z") for all operational purposes.

To Convert From:	To Greenwich Mean Time:
Eastern Standard Time	Add 5 hours
Eastern Daylight Time	Add 4 hours
Central Standard Time	Add 6 hours
Central Daylight Time	Add 5 hours
Mountain Standard Time	Add 7 hours
Mountain Daylight Time	Add 6 hours
Pacific Standard Time	Add 8 hours
Pacific Daylight Time	Add 7 hours

(2) SAUS 4 KAWN 131700 (fig 11-14). The SAUS symbol indicates surface observations for aviation from the US. The 4 is the area circuit number ((B), fig 11-11). The KAWN is the identifier for the Automated Weather Network facility at Carswell AFB, Texas. The 131700 is the date-time group (Zulu).

11-9. Types of Reports

The aviator should be familiar with the two normal types of teletype sequence reports.

a. Record (Hourly). Record reports are transmitted under the headings of SA and SAUS every hour on the hour and are frequently referred to as *hourly reports*. All the weather elements and specified remarks are transmitted in the record reports (fig 11-12 and 11-14) as required by Federal Meteorological Handbook No. 1.

b. Significant Changes and Notices to Airmen (SCAN). Between the scheduled hourly reports (a above), the WMSC and the KAWN poll the reporting stations on the various circuits to obtain SCAN reports and other data. The method of polling (or scanning) used by the Weather Service and FAA differs slightly from that used by the military.

(1) *National Weather Service and FAA polling.* The WMSC polling of the basic SA reports on the hour (H + 00) is called the A-1 poll. An A-2 poll hourly at H + 20 and an A-3 poll hourly at H + 40 are used to collect any unscheduled data between the hourly reports (fig 11-15). The unscheduled reports in the A-2 and A-3 poll could include amendments to the A-1 poll, special weather reports, pilot reports, and other selected data (fig 11-16).

(2) *Military scanning.* The military scanning method is similar to that described in b above but is done on a continuous basis following the last hourly report of the basic military circuits or any other scheduled reports. In figure 11-17, the basic report for circuit 8 is shown for 1000 Zulu on the 17th. (The ZCZC 1004 indicates the actual time of transmission as 1004 Zulu.) Below this at 1011Z, a special report was given for Hampton, Virginia (LFI) and at 1014Z another special report was transmitted for Charleston, South Carolina (CHS). The Charleston special indicates that at 1010Z the weather had changed to—measured 900-foot broken, 1,400-foot overcast with a 10-mile visibility, winds from 320 degrees at 12 knots, altimeter 29.92 inches of mercury with ragged ceiling.

GEORGIA 101303
 ABY 80SCT E250VC 20 73/72/1908/997/TE15 RE42 BINOV LC BLDUPS DSNT
 NW-N→ABY 6/16 8/2
 →ABY 6/16 TMA NDB OTS
 →ABY 8/2 ABY DME OTS 16-2100
 AGS SP 30SCT E55BKN 140BKN 10 128/83/68/1910/990→AGS→8/1
 →AGS 8/1 AGS RVR 35 OTS
 AHN M5BKN 90VC 4R-F 124/75/74/2604/993 CIG RGD
 AMG 30SCT 250SCT 12 144/89/69/2411/996→AMG→7/2 7/5
 →AMG 7/2 FZG NDB OTS
 →AMG 7/5 FZG 1-19 CLSD

FLORIDA 101305
 DAB 30SCT E250BKN 10 166/89/74/1111/002/ TCU SE-SW-NW
 EYW 18SCT 250SCT 15 163/88/75/1306/001/CB DSNT NNE MOVG W→EYW→6/5
 →EYW 6/5 MTH LRCO 122.6 CMSN
 FLL 25SCT 250SCT 10 88/73/1210/004 TCU E-SE→FLL 8/3
 →FLL 8/3 FLL 13-31 CLSD
 FMY 35SCT 12 163/91/71/0809/001/TCU N→FMY→7/10 8/1
 →FMY 7/10 FMY OM/MM/GS/LOC CMSN I-FMY 110.7
 →FMY 8/1 PGD FOR RWY LGTS 15-33 0200-SR KEY 5 TIMES WI 5
 SEC ON 122.8
 GNV 30SCT 20 161/90/70/2705/001

MISSISSIPPI 101308
 GLH 28SCT 7 87/73/3408/000→GLH→8/1
 →GLH 8/1 RWY35R-17L/4-22 CLSD UFN
 GPT E20BKN 80VC 6H 81/74/2010/000
 GWO 35SCT 5H 156/85/71/3606/999
 JAN 25SCT 6H 148/86/72/0110/998→JAN→7/4 7/6 7/14
 →JAN 7/4 JAN MALSR 33L CMSN
 →JAN 7/6 JAN 15L-33R CLSD
 →JAN 7/14 JAN ILS 15L DCMSN

SA MILITARY 101330
 SEM 12SCT E25BKN 100VC 7 136/79/74/2206/994
 CBM 35SCT 5H 156/85/71/3606/999
 NMM E30BKN 7 164/84/72/3004/005
 BIX E20BKN 90VC 6H 142/81/74/2010/000

Figure 11-13. National Weather Service and FAA hourly sequence (additional selected stations to basic circuit).

PBG	PLATTSBURGH, N Y	SAUS 4 KAWN 131700
RME	ROME, NY	PBG M370VC 20 39/25/3018G29/980/PK WND 3033/40
LIZ	LIMESTONE, ME	RME 20SCT M350VC 15 39/28/2922G30/000/CIG RGD
PSM	PORTSMOUTH, NH	LIZ 4SCT E8BKN 100VC 2SW- 28/21/E2108/933
CEF	CHICOPEE FALLS, MA	PSM 20SCT E100BKN 20 45/38/2715G20/969
FMH	FALMOUTH, MA	CEF M25BKN 400VC 15 44/32/3118/991/PRESRR WET RWY
WRI	FORT DIX, NJ	FMH 9SCT 23SCT E70BKN 2500VC 9 48/43/2223G31/979/WET RWY
DOV	DOVER, DE	WRI 25SCT E70BKN 1000VC 9 55/48/2810/004/WET RWY
ADW	ANDREWS AFB, MD	DOV 100SCT E200BKN 7 62/51/2908G15/008
FME	FORT MEADE, MD	ADW E100BKN 2500VC 7 58/41/2910G16/009
DAA	DAVISON AAF, VA	FME E120BKN 2500VC 7 58/44/3212G19/011/WET RWY
NXX	WILLOW GROVE, PA	DAA E40BKN 120BKN 2500VC 7 59/51/3208G14/009
NHK	PATUXENT RIVER, MD	NXX 10SCT E15BKN 800VC 3F 189/51/46/E1112G18/007
NEL	LAKEHURST, NJ	NHK 25SCT 1000SCT E2500VC 7 182/61/52/3007/007
NYG	QUANTICO, VA.	NEL 12SCT 100SCT E1200VC 7 164/55/49/2515G23/002
NZW	SOUTH WEYMOUTH, MA	NYG E40BKN 80BKN 200BKN 7 201/58/49/0204/011
NCO	QUONSET POINT, RI	NZW 40SCT E1000VC 7 078/53/43/2614G25/975
NHZ	BRUNSWICK, ME	NCO 40SCT E100BKN 2500VC 10 096/55/46/2514G24/981
MTN	BALTIMORE, MD.	NHZ 50SCT E80BKN 200BKN 7 020/38/33/2510/959
		MTN E40BKN 800VC 10 57/48/3308G15/014/WSHFT 49 FROPA

Figure 11-14. Military hourly sequences.

It requires approximately 3 minutes to scan all military stations. By making a continuous scanning during the hour, the aviator is provided with the most current weather information available for flight planning.

c. *SCAN Criteria.* The criteria for judging a *significant* weather change are contained in Federal Meteorological Handbook No. 1. Some illustrations of these criteria follow.

- Ceiling decreases or increases by specified values.
- Clouds not previously reported form with bases below 1,000 feet, or below the highest instrument minimum for the particular airfield.
- Visibility values decrease or increase to specified distances.
- A tornado is observed or disappears.
- A thunderstorm begins, increases in intensity, or ends.
- Freezing precipitation or ice pellets begin, change intensity, or end.
- Other precipitation begins or ends.
- Wind shifts or a doubling of average wind speed to exceed 25 knots.
- Any meteorological situation occurs that the observer believes is important to the safety or efficiency of aircraft operations.

11-10. Station Identifiers

At the prescribed time for reporting, the polling facility transmits the circuit heading and the stations report in a uniform sequence under the heading. Each station in the United States and in Mexico is identified by three letters; in Canada, by two letters. The identifiers for any station are available in the weather station (usually on clipboards). They are the same identifiers used in navigation publications. Figure 11-18 shows a key to placement of data in a weather report.

11-11. Sky Condition and Ceiling

a. *Sky Condition.* The sky condition is transmitted after the station identifier. Standardized contractions (fig 11-19) indicate the amount of sky covered by clouds or the amount obscured by surface-based phenomena.

(1) *Heights with contractions.* Sequence reports contain the height of the base of each cloud layer (measured in hundreds of feet AGL) that is indicated by a sky condition contraction. The cloud layers are encoded in ascending order. The base height precedes the appropriate sky condition contraction. Various encoded sky conditions and interpretations are shown in figure 11-20.

A2 POLL 101322

MGM
 CEW
 PNS SA→PNS 8/10 LOM OTS C8/5
 TCL
 BHM
 MSL
 TUP SW 1250 40SCT 5HK 87/74/0000/997
 ANB
 RMG
 ATL
 FTY SP 1320 M250VC 7 3207/993
 DHN

MCB →MCB 8/12 R4401 A+B ACTV 14-2400

RDU SP 1308 W4X1/4F 0211/003/R05VR22V28→RDU 8/6 FBG ARPT CLSD

CLE SA COR 1300 M320VC 10 280/80/74/1905/031/BIN0VC SW

JAX UA 1237 O/DAB MDT TURBC 180-220 B727

A3 POLL 101338

MGM
 CEW
 PNS SA →PNS C6/3
 TCL
 BHM
 MSL
 ANB
 RMG
 ATL
 FTY
 DHN SP 1824 25SCT 7 0508/007

MIA UA 1323 BTWN GREYSON AND KING INT MDT TO SVR TURBC FL260-310 B727

DCA UA 1338 LGT-MDT CHOP O/EMI 240 AND ABV DC9

MYR SA COR 1341 E5BKN 150VC 2R- 0310/001/VSBY N1

Corrections (COR) ----- corrections to earlier report.
 Pilot reports (PIREPS) (UA) ----- routine pilot reports of inflight weather.
 Urgent pilot report (UUA) ----- urgent messages are transmitted immediately.
 Special aviation weather (SP) ----- can be a record special on A-1 poll or a special
 transmitted on A-2 or A-3 poll.
 Supplementary weather (SW) ----- supplementary weather to A-1 poll. Often from
 smaller stations not in the basic circuit.

Figure 11-16. Unscheduled reports of A2 and A3 poll.

ZCZC 1004
 SAUS 8 KAWN 171000
 LFI M120VC 10R- 44/43/0114G20/994/WET RWY
 GSB M4V0VC 21/2R-F 41/40/1308/992/CIG 4V5 WET RWY
 POB -XM5VBKN 170VC 4F 41/38/3610G17/989/F2 CIG 3V7 WET RWY
 CHS 9SCT M140VC 10 43/41/3208/991/CIG RGD
 SVN M10BKN 300VC 10 45/40/3306/995
 LHW E250BKN 10 43/32/3208/995

ZCZC 1011
 SPUS 8 KAWN 171011
 LFI 1003 7SCT M120VC 10R- 0115G21/994

ZCZC 1014
 SPUS 8 KAWN 171014
 CHS 1010 M9BKN 140VC 10 3212/992/CIG RGD

Figure 11-17. Military scanning.

LOCATION IDENTIFIERS AND TYPE OF REPORT	SKY AND CEILING	VISIBILITY AND WEATHER OBSTRUCTION TO VISION	SEA LEVEL PRESSURE	TEMPERATURE AND DEW POINT	WIND	ALTIMETER SETTING	RUNWAY VISUAL RANGE	CODED PIREPS
MKC	15SCT M250VC	1R-K	132	/58/56	/1817	/993/	R04LVR20V40	/OVC55

Figure 11-18. Key to aviation weather report.

<u>CONTRACTION</u>	<u>NAME</u>	<u>AMOUNT COVERED OR OBSCURED</u>
CLR	CLEAR	LESS THAN .1 COVERED
SCT	SCATTERED	.1 THRU .5 COVERED
BKN	BROKEN	.6 THRU .9 COVERED
OVC	OVERCAST	OVER .9 COVERED
-X	PARTIAL OBSCURATION	LESS THAN 1.0 OBSCURED
X	SKY OBSCURED	1.0 OBSCURED

A MINUS (-) SIGN PRECEDING A CONTRACTION (-SCT, -BKN, OR -OVC) INDICATES THE LAYER IS THIN.

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Figure 11-19. Sky condition contractions.

(2) *Amount of sky cover.* The sky coverage is accumulative in the sequence reports; i.e., each sky coverage contraction (fig 11-19) represents the total coverage at and below the reported cloud deck. (Only those clouds visible from the surface can be reported.) The amount of sky cover designated by successive contractions at a station will either remain the same or show an increase in ascending layers. The amount of sky coverage will never decrease vertically; i.e., a report may appear as 12SCT 25SCT 55-BKN 250-OVC, but never as 12-OVC 25-BKN 55SCT 250SCT.

(3) *Obscuration (X) and partial obscuration (-X).*

When obscuring phenomena such as fog, haze, smoke, dust, and the several forms of precipitation exist at the surface, the sky may be either totally or partly obscured.

(a) An obscuration (X) is reported when 10/10 of the sky is hidden by surface-based obscuring weather phenomena. In this situation, the limit of the observer's vertical visibility over the point of observation is reported as the ceiling height. The obscuration may be reported as 0X, 2X, 10X, etc. (interpreted as ceiling zero, sky obscured; ceiling 200 feet, sky obscured; ceiling 1,000 feet, sky obscured). Thus the alti-

<u>REPORTED AS</u>	<u>INTERPRETED</u>
20SCT	TWO THOUSAND SCATTERED
5-BKN	FIVE HUNDRED THIN BROKEN
120OVC	TWELVE THOUSAND OVERCAST
250SCT	TWO FIVE THOUSAND SCATTERED
5SCT 10-OVC	FIVE HUNDRED SCATTERED, ONE THOUSAND THIN OVERCAST

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Figure 11-20. Encoded sky conditions and interpretations.

CEILING CLASSIFIERS

E ESTIMATED

M MEASURED (NORMALLY WITH A CEILOMETER)

W INDEFINITE (USED WITH OBSCURED CONDITION)

FORMINTERPRETATION

20SCT M50BKN

TWO THOUSAND SCATTERED, MEASURED CEILING
FIVE THOUSAND BROKEN

-XE80VC

SKY PARTIALLY OBSCURED, ESTIMATED CEILING
EIGHT HUNDRED OVERCAST

W5X

INDEFINITE CEILING FIVE HUNDRED, SKY
OBSCURED

28SCT 50-BKN E250BKN

TWO THOUSAND EIGHT HUNDRED SCATTERED,
FIVE THOUSAND THIN BROKEN, ESTIMATED
CEILING TWO FIVE THOUSAND BROKEN

40SCT 100SCT E250VC

FOUR THOUSAND SCATTERED, ONE ZERO
THOUSAND SCATTERED, ESTIMATED CEILING
TWO FIVE THOUSAND OVERCAST

Figure 11-21. Ceiling classifiers and examples of their use.

tude indicated with an obscuration is the *vertical visibility* into the obscuration, *not* the height to the base of the obscuration.

(b) When the sky is only partly obscured by surface-based weather phenomena (less than 10/10), a partial obscuration (-X) is reported. Since partial obscurations do not restrict the vertical visibility over the point of observation, any cloud layers observed above the partial obscuration are reported after the -X. The heights of the cloud bases and ceiling, if any, are reported, but the -X is not preceded by an altitude figure.

(c) Weather conditions producing partial and total obscurations are based on the surface and restrict the horizontal visibility, whereas cloud layers (SCT, BKN, AND OVC) have definite bases above 50 feet and do not directly affect the horizontal surface visibility.

b. *Ceiling.* The ceiling is the lowest condition reported as BKN, OVC, or X that is not prefixed by a minus (-). A thin cloud layer or a partial obscuration is never a ceiling. When a ceiling is reported in sequence reports, the method by which the ceiling was determined or classified *must* precede the height of the contraction (BKN, OVC, X) which appears as the ceiling layer. The letters used as ceiling classifiers are shown in figure 11-21.

11-12. Visibility

The visibility is reported in statute miles after the sky condition contraction (with one space separation) indicating the greatest horizontal distance that an object of specified characteristics can be seen and identified. When restricted or irregular, the visibility may be reported by one or more of the following refinements.

a. *Prevailing Visibility.* The prevailing visibility is the greatest visibility that exists over half or more than half of the horizon. When the visibility varies in different quadrants from the point of observation, the prevailing visibility is reported. Variations from the reported prevailing visibility value are included at the end of the report (remarks section). The visibility may be variable at a station; if the prevailing visibility is varying between reportable values (*b* below) and less than 3 miles, the reported visibility value is followed by the letter V.

b. *Reportable Values.* When the visibility is less than 3 miles, it is reported in miles and fractions of a mile. When the visibility is between 3 and 15 miles, it is reported to the nearest mile. When visibility exceeds the most distant marker used, the next higher reportable value will be reported.

c. *Runway Visual Range (RVR).* Although the visibility or prevailing visibility will normally determine

the type of flight plan to file, an aviator landing at a terminal under instrument conditions will find the *runway visual range (RVR)* to be the most reliable guide to visibility along the selected runway. RVR is the horizontal distance an aviator will see down the runway from the approach end. It is based upon the sighting of high intensity runway lights or upon the visual contrast of other sighting targets—whichever yields the greater visual range. Runway visual range is determined by an instrument called a transmissometer mounted beside the instrumented runway near the touchdown point. RVR has an advantage over the prevailing visibility because the high intensity lights can often be seen on the approach path even though the actual runway is not visible. Under IFR conditions, the RVR provides a more realistic value of the actual visibility existing at an airfield and is used as the basis for approach minimums in many cases. RVR is reported in the remarks section of the hourly sequence report when it is 6,000 feet or less, and is given in hundreds of feet. For example, R28-VR38 indicates that on runway 28 the runway visual

range is 3,800 feet. R23VR30V indicates that on runway 23 the runway visual range is 3,000 feet variable.

Note. The RVR value shown in aviation weather reports represents a mean value and is shown for information only. It is not to be used for flight planning minimums.

11-13. Weather and Obstructions to Vision

Weather phenomena and obstructions to vision are reported by the use of letter symbols after the reported visibility (no space separation).

a. Weather Elements. Atmospheric phenomena considered as weather elements in a report are tornadoes, waterspouts, funnel clouds, thunderstorms, and precipitation in any form. The letters used for reporting weather elements are shown in figure 11-22. These letters are used whenever the phenomena are occurring at observation time, regardless of their effect on visibility and ceiling.

WEATHER SYMBOLS

A	HAIL	S	SNOW
IC	ICE CRYSTALS	SG	SNOW GRAINS
IP	ICE PELLETS	SP	SNOW PELLETS
IPW	ICE PELLET SHOWERS	SW	SNOW SHOWERS
L	DRIZZLE	T	THUNDERSTORMS
R	RAIN	ZL	FREEZING DRIZZLE
RW	RAIN SHOWERS	ZR	FREEZING RAIN

INTENSITIES INDICATED AS FOLLOWS:

- LIGHT NO SIGN INDICATES MODERATE
+ HEAVY (SEVERE WITH THUNDERSTORM)

INTENSITIES ARE NOT USED WITH TORNADO, WATERSPOUT, OR FUNNEL CLOUD. THESE ARE WRITTEN OUT IN FULL. ALSO, INTENSITIES ARE NOT REPORTED WITH HAIL OR ICE CRYSTALS.

Figure 11-22. Symbols for weather elements.

Note: Intensities appear in the report as a suffix to the weather element. They are spoken as if they were a prefix (e.g., S - is light snow; R + is heavy rain).

b. Obstructions to Vision. Obstructions to vision are not reported when the visibility is more than 6 miles. When the visibility is reported as 6 miles or less, weather phenomena or obstructions to vision (or both) must be reported to explain the restricted visibility. The letters used for reporting obstructions to vision are given in figure 11-23.

F	FOG	IF	ICE FOG
GF	GROUND FOG	H	HAZE
BS	BLOWING SNOW	K	SMOKE
BN	BLOWING SAND	D	DUST
BD	BLOWING DUST	BY	BLOWING SPRAY
INTENSITIES (+ OR -) ARE NOT INDICATED WITH OBSTRUCTIONS TO VISIBILITY			

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Figure 11-23. Symbols for obstructions to vision.

11-14. Sea Level Pressure in Millibars

Sea level pressure is reported in three figures representing tens, units, and tenths of millibars. To interpret the value, one decimal place is pointed off and the reported figures are preceded with 9 or 10, whichever will make the complete figure read nearer 1013.2 millibars. Examples: 012-1001.2 mb; and 999-999.9 mb. The military (SAUS) circuits transmit the pressure in millibars every 3 hours beginning at 0000Z. The civil (SA) circuits include pressure data in each hourly transmission.

11-15. Temperature

The surface temperature is reported in sequence reports in the United States to the nearest whole degree Fahrenheit. Most other countries report the temperature in degrees Celsius. A minus sign preceding the temperature figure indicates that the temperature is below zero.

11-16. Dew Point Temperature

The surface dew point temperature is reported in degrees Fahrenheit. The teletype sequence reports contain the latest data available for determining the temperature-dew point spread and the tendency for the spread to decrease or increase. The rate at which

the temperature-dew point spread will change is affected by the sky condition, precipitation, wind-speed, advection of moist air (source and trajectory of wind), diurnal heating, and nocturnal cooling. The spread tendency during the past few hours can be interpreted from preceding reports (para 2-12b).

Note: Surface dew point temperature will always be equal to or less than surface temperature.

11-17. Wind

The surface wind velocity (direction and speed) is reported in degrees and knots by four numerals. The first two numerals indicate the direction (to the nearest 10°) with reference to true north (36); the second two numerals indicate the windspeed to the nearest knot. *For example*, 0405 indicates a surface wind from 040° (northeast) at 5 knots; 0915 indicates 090° at 15 knots. Table B-5 in appendix B shows the relationship between degrees and the 16 compass points.

a. Calm winds are reported as 0000.

b. Gusts are rapid fluctuations in windspeed with a variation of 10 knots or more between peaks and lulls. If gusty conditions are reported, a *G* follows the average windspeed, with the peak speed recorded following the *G*. *For example*, 15G25 indicates that the average windspeed is 15 knots with gusts to a peak speed of 25 knots as of the time of the observation.

Note: The difference between the average and the peak wind speed does not represent the true spread. Gust spread represents the range of windspeed from minimum to maximum during the gust cycle. This value is not normally reported due to the difficulty in observing. For application of gust spread to aircraft limitations (e.g., starting and stopping of helicopter rotor systems), the aviator should ask the tower for the specific minimum and maximum wind velocities.

c. Squalls are defined as sudden increases of wind-speed of at least 15 knots, and sustained at 20 knots or more for at least 1 minute. In reporting squalls, *Q* is used instead of *G*. *For example*, 20Q36.

d. Wind shifts are reported in the remarks section of the sequence report, with the Greenwich mean time of the shift; i.e., WSHFT 0600.

11-18. Altimeter Setting

The altimeter setting is derived from the pressure at field elevation corrected to mean sea level. It is represented (reported) by a three-digit group, without a decimal point, for units, tenths, and hundredths of inches Hg. To interpret the value, point off two deci-

mal places and precede the reported figures with 2 or 3, whichever will make the complete figure read nearer 29.92 inches Hg. *For example*, 003-30.03 inches Hg; 987-29.87 inches Hg.

11-19. Remarks

a. General. The remarks section of the report is transmitted after the altimeter setting (at manned stations). This section is appended to the report to give the aviator and meteorologist detailed information for flight planning. Remarks are reported in standardized contractions of words and phrases. Figure 11-24 shows several contractions with the interpretations in common usage.

b. Additive Data (Coded). Every 6 hours (0000Z, 0600Z, 1200Z, 1800Z) and at 3 hour intervals (0300Z, 0900Z, 1500Z, 2100Z) special coded additive information is furnished by the reporting stations for use in plotting the surface weather map and other charts. These would include: pressure tendency and amount of change in last 3 hours, amount of precipitation in the last 6 hours, 12 and 24 hour minimum and maximum temperatures, low, middle, and high clouds present with their movement information, etc. This information is very important to the weather specialist but is not normally needed by the aviator.

c. Pilot Reports (PIREP). Army aviators are required to report weather conditions which have not been forecast to air traffic control. These reports will assist other aviators in planning their flights, and are especially useful to the forecaster as they provide him with actual observed flight conditions both at altitude and between weather reporting stations. The aviator reporting meteorological phenomena should give the *time* of the observation, *location* of the aircraft with reference to a well-known point, *extent* (intensity) of the reported phenomena at the time of the observation, and the *altitude* of the reported phenomena (if applicable). When reporting icing or turbulence intensities, the type aircraft should also be reported. PIREP may appear in the remarks section of teletype sequence reports or on a separate transmission (fig 11-25).

d. NOTAM (Notices to Airmen). NOTAM provide a rapid means for distributing information such as runway conditions, radio navigation facilities, special airport activities, and activation of restricted airspace. The method used to transmit NOTAM differs slightly between the civil and military weather facilities.

(1) *National Weather Service and FAA.* The National Weather Service and the FAA Flight Service stations receive NOTAM in the remarks section of the hourly sequence report (A-1 poll) or in the A-2 or A-3 poll. These facilities also have the responsibility for originating NOTAM for their own area and a

number system is used to catalog them. Each NOTAM issued for a station is assigned a serial number starting with 1 for the first month of the year and 1 for the first NOTAM of the month. The month of issuance and the NOTAM number are separated by a slant (/) to identify each NOTAM issued; e.g., 6/5 would be the 5th NOTAM issued for that station in June. The NOTAM data is issued in plain language using a standard system of contractions (fig 11-26). The computers of the Weather Message Switching Center monitor all NOTAM inputs to the SA polls. They are checked for correct numbering and format and are stored in the computer. The use of coded arrows, identifiers, and NOTAM serial number in the regular sequence report of each station will show which NOTAM are current (fig 11-26). A NOTAM summary will follow the basic circuit group of sequence reports. The selected stations shown by state will give the complete NOTAM on a separate line following the report (fig 11-27).

(2) *Military weather facilities.* NOTAM are not normally appended to Air Weather Service Reports (SAUS), but are transmitted during the continuous scanning of the circuits (para 11-9b(2)) by the Automated Weather Network (KAWN). Additionally, at 1100Z and 2300Z a complete summary of NOTAM is transmitted similar to the one each hour in the civil coverage.

11-20. Meteorological Terminal Aviation Report (METAR)

METAR is an observation code (fig 11-28) transmitted by all Air Force Air Weather Service units outside continental North America, Hawaii, Guam, and Puerto Rico. The general formats for METAR are different from the teletype sequence reports covered in the previous paragraphs, but the same information is given in both reports. (Refer to figure 11-28 for example of report information.)

a. Station Identifiers (METAR). All stations will be identified by four letters—the normal three-letter identifier, preceded by another international letter (fig 11-29). *For example*, all stations in Mexico will be preceded by the letter M; all stations in Alaska will be preceded by the letter P; and all stations in England, Norway, and Sweden will be preceded by the letter E (fig 11-29 and 11-30).

b. Wind Velocity (METAR). The surface wind velocity is reported in degrees and knots by five numerals. The first three numerals indicate the direction (to the nearest 10°) with reference to true north. A wind from thirty degrees would be reported as 030, while a wind from three hundred degrees would be reported as 300. The next two numerals indicate the windspeed to the nearest knot. *For example*, 07015 indicates a surface wind from 070° at 15 knots.

1. T OVR STN MOVG E (THUNDERSTORM OVER STATION MOVING EAST)
2. RB18 (RAIN BEGAN AT 18 MINUTES PAST THE HOUR PRIOR TO THE TIME INDICATED IN THE CIRCUIT HEADING)
3. ZRE56 (FREEZING RAIN ENDED 56 MINUTES PAST THE PREVIOUS HOUR)
4. IR (ICE ON RUNWAY, FOLLOWED BY DECELEROMETER VALUE)
5. WR (WET RUNWAY, FOLLOWED BY DECELEROMETER VALUE)
6. BINOV (BREAKS IN THE OVERCAST)
7. SC W (LESS THAN 1/10 STRATOCUMULUS WEST OF STATION)
8. CB ALQDS (CUMULONIMBUS ALL QUADRANTS)
9. FROPA (FRONTAL PASSAGE)
10. CIG RGD (CEILING RAGGED)
11. LN SC N-E HRZN (LINE OF STRATOCUMULUS ON THE HORIZON NORTH THROUGH EAST)
12. PRESFR (PRESSURE FALLING RAPIDLY)
13. PRESRR (PRESSURE RISING RAPIDLY)
14. THN SPOTS IN OVC (THIN SPOTS IN OVERCAST)
15. R13VR40V (RUNWAY 13 VISUAL RANGE 4,000 FEET, VARIABLE)
16. SHLW GF ALQDS (SHALLOW GROUND FOG ALL QUADRANTS)
17. MTN TOPS OBSCD (MOUNTAIN TOPS OBSCURED)
18. CIG 3V5 (CEILING 300 FEET VARIABLE TO 500 FEET)
19. OCNL L- (OCCASIONAL LIGHT DRIZZLE)
20. F INCR (FOG INCREASING)
21. BKN V OVC (BROKEN VARIABLE OVERCAST)
22. VSBY S-W 3/4 (VISIBILITY SOUTH THROUGH WEST THREE-FOURTHS OF A MILE)
23. R32VV3/8 (RUNWAY VISIBILITY ON RUNWAY 32 IS THREE-EIGHTHS OF A MILE)
24. LTGIC (LIGHTNING IN CLOUD)
25. LTGICCG (LIGHTNING IN CLOUD AND CLOUD TO GROUND)
26. DRK W (DARK TO THE WEST - DENSE CLOUDS)
27. R06VRNO (RUNWAY VISUAL RANGE RUNWAY 06 NOT AVAILABLE)
28. WND 15V24 (WIND VARYING 150° TO 240°)
29. F3 (FOG OBSCURING 3/10 OF THE SKY)
30. DRFTG S NW (DRIFTING SNOW TO THE NORTHWEST)
31. 550VC65 (PILOT REPORTS BASE OF OVERCAST AT 5,500 FEET WITH TOP OF OVERCAST AT 6,500 FEET)
32. T OVHD (THUNDER OVERHEAD)
33. TCU NE-SE-S RWU S (TOWERING CUMULUS NORTHEAST, SOUTHEAST, AND SOUTH; RAINSHOWERS OF UNKNOWN INTENSITY SOUTH OF THE STATION)
34. DSNT LTNG NE-SE (DISTANT LIGHTNING NORTHEAST THROUGH SOUTHEAST)
35. LGT TO MDT CAT (LIGHT TO MODERATE CLEAR AIR TURBULENCE)
36. BRAM15 (BRAKING ACTION MODERATE - DECELEROMETER VALUE 15. DECELEROMETER VALUES RANGE FROM IDEAL (0) TO POOR (30))
37. BRAP28 (BRAKING ACTION POOR - DECELEROMETER VALUE 28)

Figure 11-24. Remarks.

1. BIF PIREP 142300Z ABI-BIF 350 WND 260/172K LGT TURBC T-33.
PILOT REPORTED TO BIGGS AFB (BIF) ON THE 14TH DAY OF THE MONTH AT 2300Z THE WIND AT 35,000 FEET WAS 260° AT 172 KNOTS BETWEEN BIGGS AND ABILENE (ABI). LIGHT TURBULENCE WAS ALSO ENCOUNTERED. THE PILOT WAS FLYING A T-33 AIRCRAFT.
2. PIA PIREP 150138Z PIA-SBN MDT ICG RAIN AND SNW STICKING 40-50 LGT ICG 70 DC3.
PILOT REPORTED TO PEORIA (PIA) AT 0138Z ON THE 15TH DAY OF THE MONTH THAT HE WAS ENCOUNTERING MODERATE ICING IN RAIN AND STICKING SNOW BETWEEN 4,000 AND 5,000 FEET WITH LIGHT ICING AT 7,000 FEET ON A FLIGHT BETWEEN PEORIA AND SOUTH BEND (SBN). TYPE OF AIRCRAFT, DC-3.
3. BWG PIREP 150225Z BNA-BWG XTREM TURBC 30 C182.
PILOT REPORTED TO BOWLING GREEN (BWG) THAT EXTREME TURBULENCE WAS ENCOUNTERED AT 3,000 FEET BETWEEN NASHVILLE (BNA) AND BOWLING GREEN. TYPE OF AIRCRAFT, C-182.
4. BGS PIREP 141522Z 45 NW BGS 70-150 MDT-SVR TURBC T38.
T-38 PILOT REPORTS MODERATE TO SEVERE TURBULENCE BETWEEN 7,000 AND 15,000 FEET 45 MILES NORTHWEST OF BIG SPRINGS.
5. RND PIREP 141524Z ON TKOF RND 150VC46 CIG RGD.
PILOT REPORTED AFTER TAKEOFF AT RANDOLPH (RND) THE BASE OF THE OVERCAST WAS 1,500 FEET AND THE TOP OF THE OVERCAST WAS AT 4,600 FEET; CEILING RAGGED.
6. HAR PIREP 141240Z OVR HAR TMP -2C NEG TURBC IN CLR FLT ALT 45 U6.
AVIATOR IN U6 REPORTED TEMPERATURE -2°C, WITH NEGATIVE TURBULENCE AND CLEAR AIR AT 4,500 FEET OVER HARRISBURG (HAR).
7. ATL PIREP 141430Z 60E ATL FLT LVL 330 NEG TURBC UNDERCAST TOPS UNK ACFT CLASSIFIED.
PILOT REPORTED TO ATLANTA 60 MILES EAST OF ATLANTA AT 33,000 FEET THE TURBULENCE WAS NEGATIVE; UNDERCAST BELOW THE AIRCRAFT WITH HEIGHT OF TOPS UNKNOWN. TYPE OF AIRCRAFT CLASSIFIED.
8. STATIONS FREQUENTLY TRANSMIT A COLLECTION OF PIREP SUMMARIES AS FOLLOWS:
ACF UA 141520
PIREP SMRY
OVR OKC LGT RIME ICG 120 C97. 40SSW OKC LGT-MDT TURBC 80 C47.
31 WSW TUL LGT RIME ICG 70-100 C47. 44 WSW TUL OVC95 CLR ABV.
OVR IFI LGT RIME ICG LGT TURBC 70 C47. LIT-TXK 65KT HEADWIND 60.
OVR LFK 01 MDT TURBC BNZA. 25 S LFK IN-OUT TOPS 90.

ELP UA 142025
PIREP SMRY
35NE TUS MDT TURBC BKN CLDS 105 PA24.
OVR FST LGT-MDT CAT 420 F106. OVR SFL TOPS CLDS E140 CLDS TPG MTNS.
70 SE SAT MDT TO SVR CAT 420 F106.
ROW-LBB 45BKN LGT TURBC 45 C182.
62SE ABQ BKN125 FRONT MOVG S 20KTS MTNS OBSCD W.

Figure 11-25. Pilot reports.

<u>CODE FORM</u>	<u>INTERPRETATION</u>
→	NOTAM INDICATOR
2/3	NOTAM SERIAL NUMBER - 3RD NOTAM OF 2ND MONTH
↘	CURRENT NOTAM INDICATOR - NOTAM SERIAL NUMBERS THAT FOLLOW ARE CURRENT
✓	NOTAM TO FOLLOW - SYMBOL PRECEDES EACH SUBSEQUENT, NEW OR CANCELLED NOTAM
SAMPLE: LEX →LEX 2/8 GP OTS↘C2/6↘2/4 2/7 THE EIGHTH NOTAM IN FEBRUARY INDICATES GLIDEPATH OUT OF SERVICE; SIXTH NOTAM IN FEBRUARY IS CANCELLED; FOURTH AND SEVENTH NOTAMS OF FEBRUARY ARE STILL CURRENT.	

Figure 11-26. NOTAM interpretation.

(1) A calm wind is reported as 00000.

(2) A maximum wind is reported when it exceeds the average wind by 5 knots or more. *For example*, 18012/35 indicates the wind is from 180° at 12 knots with a maximum wind at 35 knots.

(3) A variable wind is reported as VRB. *For example*, VRB 05 indicates the wind direction is variable and the windspeed is 5 knots.

c. *Visibility (METAR)*. The surface horizontal visibility is reported in meters. When the visibility is less than 5,000 meters, it is reported to the nearest 100 meters. If the visibility is 5,000 to and including 9,000 meters, it is reported to the nearest 1,000 meters. Visibilities of 10,000 meters or greater are encoded as 9999. *For example*, 0700 indicates the visibility is 700 meters and 8000 indicates the visibility is 8,000 meters.

d. *Runway Visual Range (RVR) (METAR)*. The RVR (METAR) is the same as described in paragraph 11-12c. The RVR is reported to the nearest tens, hundreds, or thousands of meters. The runway number will not normally be given. *For example*, R0500 indicates the RVR is 500 meters and R2000 indicates the RVR is 2,000 meters.

e. *Weather and Obstruction to Vision (METAR)*. The present and/or immediate past weather is reported in a code of numbers and letters (fig 11-31). The numbers permit a full description of the weather reported; whereas, the letter abbreviations give only a categorical description. *For example*, 50DZ indicates the present weather is drizzle. In figure 11-28, station PGMT is reporting a visibility of 600 meters with fog, while station RMQS is reporting a visibility

of 800 meters with thunderstorms with duststorms or sandstorms.

Note: This weather code relates to the international map symbols found in figure 12-4.

f. *Cloud Group*. The cloud group has three parts—the cloud amount (reported in eighths), cloud type (fig 11-32), and base of cloud layer above the ground. The cloud group will be repeated as necessary to indicate the cloud distribution. The groups will be arranged in an ascending order of the height of cloud layer bases. When clear skies are present, the group is not used. The ceiling is the height at which the summation of predominantly opaque sky cover, at and below the height, exceeds 4/8. Cloud bases are entered as three digits and represent heights in hundreds of feet. *For example*, 5SCO25 indicates 5/8 stratocumulus at 2,500 feet above the ground; the groups 3CU015, 5ACI50, 8CI300 indicate 3/8 cumulus at 1,500 feet, 5/8 altocumulus at 15,000 feet, and 8/8 cirrus at 30,000 feet. An exception to this is a total obscuration. When this occurs and if the vertical visibility is 500 feet, it would be reported as 9FG005. *For example*, in figure 11-28, station PGMT is reporting the following: wind velocity is 010°/6 knots, horizontal visibility 600 meters, RVR 500 meters, fog, and a total obscuration with the vertical visibility (ceiling) 300 feet.

g. *CAVOK (METAR)*. The word CAVOK (ceiling and visibility ok) is used in lieu of visibility, RVR, present weather, and cloud group data (at other than

SA15 101300
 MGM 10SCT E25BKN 950VC 7 134/78/75/2205/994 RB40E51
 CEW 12SCT E25BKN 1000VC 10 147/80/72/2408/997/RE30
 PNS 8SCT M12BKN 500VC 7 153/81/71/2510G17/999/DRK S
 TCL E18BKN 4HK 140/84/72/3610/995
 BHM M17BKN 5K 135/81/72/3207/995→BHM→7/10
 MSL 35SCT 300SCT 10 147/84/70/0109/998→MSL→8/2
 ANB 12SCT E250VC 3H 127/78/70/2908/993→ANB→8/9
 RMG E 5 BKN 30 OVC 1 TRW+ -13/73/71/11--/994/RVNOVVV/MTB16
 RB23 OCNL THDR WNW MOVG ENE
 ATL E12BKN 800VC 10 127/76/72/2406/994/RE10→ATL→7/4 8/2 8/3
 FTY E25BKN 1500VC 5H 78/70/2805/993/THN SPOTS 10VC
 DHN E20BKN 80BKN 2500VC 10 142/79/71/1914G20/996→DHN→7/9

→NOSUM101302
 →BHM 7/10 BHM 5-23 CLSD 0530-1200 MON-FRI THRU 11/15
 →MSL 8/2 LRT NDB OTS
 →ANB 8/9 GAD 6-24 CLSD 2KDAY 1200-SS EXCP PPO
 →ATL 7/4 CTJ NDB OTS
 →ATL 8/2 ATL ILS 8 OTS TIL 9/18
 →ATL 8/3 ATL ALS 8 OTS
 →DHN 7/9 TOI 1-19 CLSD

GEORGIA 101303
 ABY 80SCT E2500VC 20 73/72/1908/997/TE15 RE42 BIN0VC LN BLDUPS DSNT
 NW-N→ABY→6/16 8/2
 →ABY 6/16 TMA NDB OTS
 →ABY 8/2 ABY DME OTS 16-2100
 AGS SP 30SCT E55BKN 140BKN 10 128/83/68/1910/990→AGS→8/1
 →AGS 8/1 AGS RVR 35 OTS
 AHN M5BKN 90VC 4R-F 124/75/74/2604/993 CIG RGD
 AMG 30SCT 250SCT 12 144/89/69/2411/996→AMG→7/2 7/5
 →AMG 7/2 FZG NDB OTS
 →AMG 7/5 FZG 1-19 CLSD

Figure 11-27. NOTAM summary (NOSUM).

PHIK 07012 7500 2CU018 4CU035 32/19 2974INS/CIG035 VIS S 9000
 PGST VRB05 9000 4AS070 10/05 2998INS/FU LYR SE
 PGMT 01006 0600 R0500 47FG 9FG003 12/11 2995INS/CIGW003
 PGLQ 12015 9000 3ST025 5SC050 15/10 3005INS/CIG050
 RMNL 18015/30 9000 6CI300 31/16 3016INS/CIG300
 RMQS 25025 0800 R0600 98TSSA 2FG/// 8CB015 28/21 2964INS/CIGM015

Figure 11-28. Meteorological terminal aviation report (METAR).

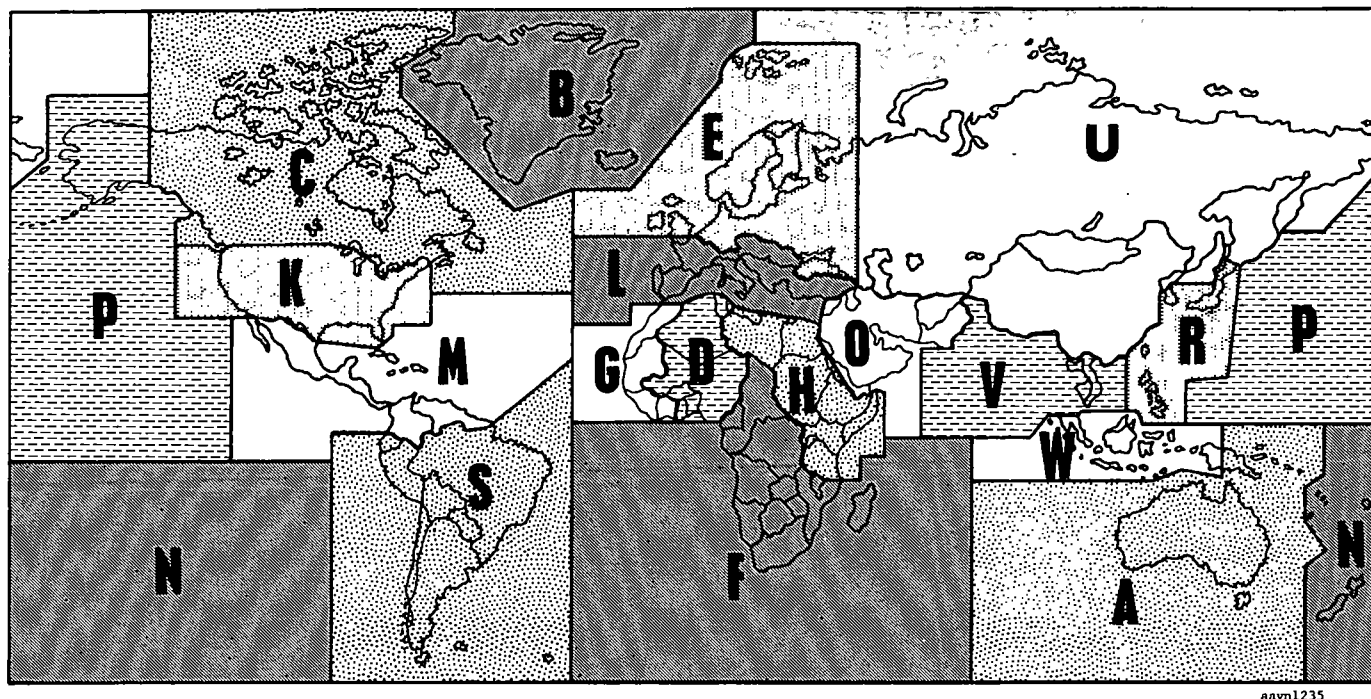


Figure 11-29. Index to identifying letters (METAR and TAF).

US Air Force stations) whenever the following conditions exist:

- Visibility is 10 km or more.
- No clouds below 1,500 meters.
- No precipitation and no thunderstorms.

h. Temperature and Dew Point (METAR). The surface temperature and the surface dew point are reported in degrees Celsius. The letter M preceding the temperature and/or dew point indicates that it is below zero. *For example*, in figure 11-28, station PGLQ is reporting a temperature of 15° C. and a dew point of 10° C., while station PHIK is reporting a temperature of 32° C. and a dew point of 19° C.

i. Altimeter Setting (METAR). The altimeter setting is reported with units of measurement in either inches of mercury or millibars. *For example*, in figure 11-28, station RMNL is reporting an altimeter setting of 30.16 inches of mercury, and station PHIK is

PHIK	HICKAM AFB, HAWAII
RLTE	LEYTE ISLAND, PHILIPPINES
ALWH	LAWN HILL, AUSTRALIA
LGVA	GENEVA, SWITZERLAND
PGST	GUSTAVUS AIRPORT, ALASKA
EGLA	GLASGOW, SCOTLAND
LGIO	GIOIA, ITALY
RMNL	MANILA, PHILIPPINES

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Figure 11-30. International station identifiers (METAR and TAF).

04 FU	SMOKE	66 FZRA	FREEZING RAIN
06 HZ	DUST HAZE	67XXFZRA	HEAVY FREEZING RAIN
08 PO	DUST DEVILS	68 RASN	RAIN AND SNOW
11-12 MIFG	SHALLOW FOG	69XXRASN	HEAVY RAIN AND SNOW
17 TS	THUNDERSTORMS	70-73 SN	SNOW
18 SQ	SQUALL	74-75 XXSN	HEAVY SNOW
19 FC	FUNNEL CLOUD	76 IC	ICE CRYSTALS
20 REDZ	RECENT DRIZZLE	77 SN	SNOW
21 RERA	RECENT RAIN	79 PE	ICE PELLETS
22 RESN	RECENT SNOW	80 RASH	RAIN SHOWER
23RERASN	RECENT RAIN AND SNOW	81-82 XXSH	HEAVY SHOWERS
24REFZRA	RECENT FREEZING RAIN	83 RASN	SHOWERS OF RAIN AND SNOW
25 RESH	RECENT SHOWERS	84XXRASN	HEAVY SHOWERS OF RAIN AND SNOW
26 RESH	RECENT SNOW SHOWERS	85 SNSH	SNOW SHOWERS
27 REGR	RECENT HAIL	86 XXSN	HEAVY SNOW SHOWERS
29 RETS	RECENT THUNDERSTORMS	87-88 GR	SOFT HAIL
30-32 SA	DUSTSTORMS OR SANDSTORMS	89 GR	HAIL
33-35 XXSA	HEAVY DUSTSTORMS OR SANDSTORMS	90 XXGR	HAIL
36-37 DRSN	DRIFTING SNOW	91 RA	RAIN
38-39 BLSN	BLOWING SNOW	92 XXRA	HEAVY RAIN
40-41 BOFG	FOG PATCHES	93 GR	HAIL
42-47 FG	FOG	94 XXGR	HAIL
48-49 FZFG	FREEZING FOG	95 TS	THUNDERSTORMS
50-53 DZ	DRIZZLE	96 TSGR	THUNDERSTORMS WITH HAIL
54-55 XXDZ	HEAVY DRIZZLE	97 XXTS	HEAVY THUNDERSTORMS
56 FZDZ	FREEZING DRIZZLE	98 TSSA	THUNDERSTORMS WITH DUST OR SANDSTORMS
57XXFZDZ	HEAVY FREEZING DRIZZLE	99 XXTSGR	HEAVY THUNDERSTORMS WITH HAIL
58-63 RA	RAIN		
64-65 XXRA	HEAVY RAIN		

Figure 11-31. Present and Forecast Weather (METAR and TAF).

reporting an altimeter setting of 29.74 inches of mercury.

j. Ceiling (METAR). The height of the ceiling is reported by using the same code figures that are used for reporting the base of clouds. *For example*, in figure 11-28, station PHIK is reporting a ceiling of 3,500 feet, while station RMNL is reporting a ceiling of 30,000 feet.

k. Remarks (METAR). The remarks are appended to the report to give the aviator detailed information for flight planning. Some of the remarks are reported by weather symbols, while others are reported in standardized contractions of words and phrases.

CI	CIRRUS
CC	CIRROCUMULUS
CS	CIRROSTRATUS
AC	ALTOCUMULUS
AS	ALTOSTRATUS
NS	NIMBOSTRATUS
SC	STRATOCUMULUS
ST	STRATUS
CU	CUMULUS
CB	CUMULONIMBUS

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Figure 11-32. Cloud Type (METAR and TAF).

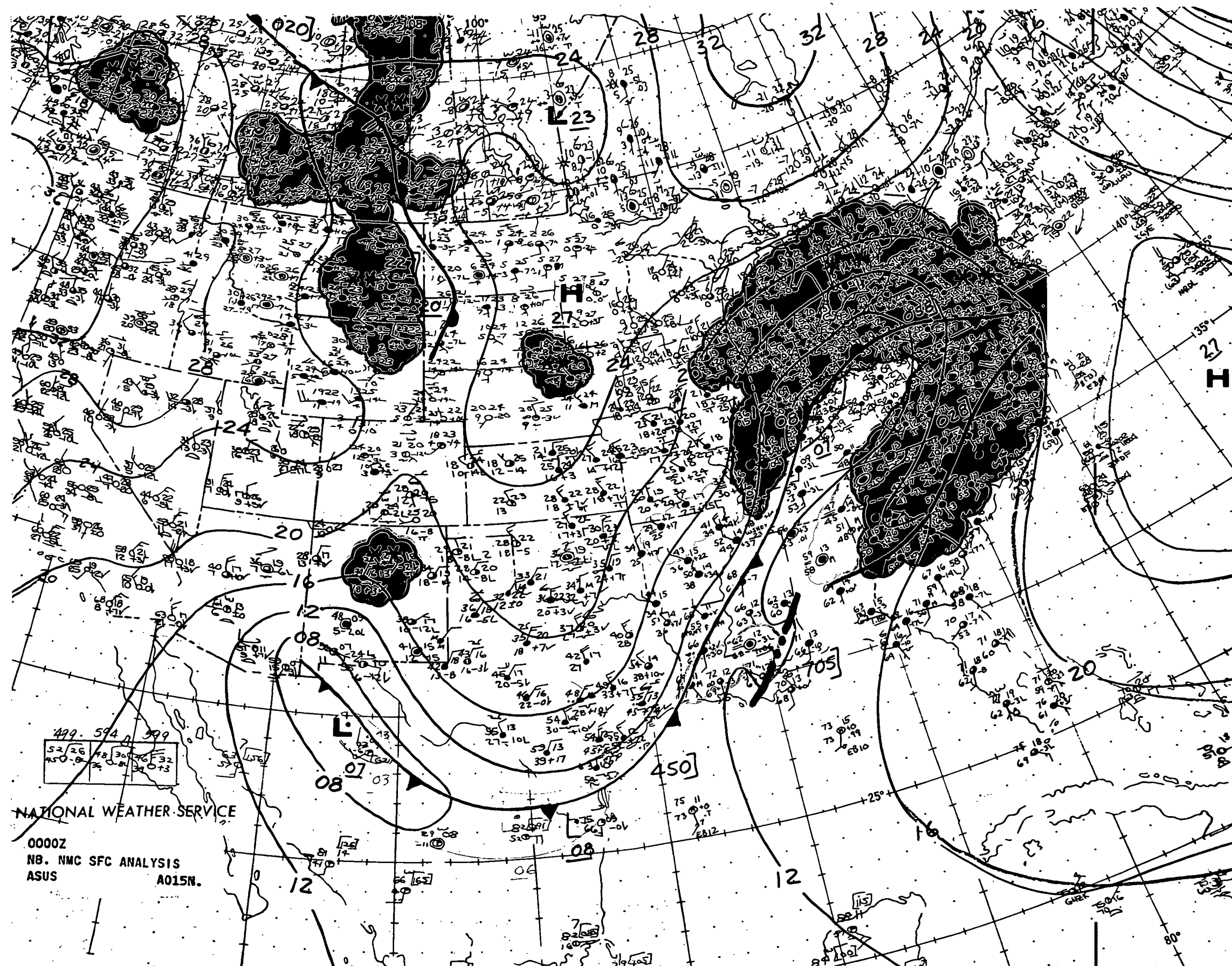


Figure 12-1. Typical surface analysis.



CHAPTER 12

SURFACE FACSIMILE MAPS

12-1. General

Many surface weather maps are prepared and transmitted each day by the National Meteorological Center (NMC). These maps are based on surface observed data recorded at a specific time by various weather stations for a particular area. Approximately 350,000 reports of existing weather conditions are received each day at the NMC just outside of Washington, D.C. A portion of the data necessary for the NMC mission is supplied by the following sources (figures are approximations): 900 airways surface reports every hour, 2,000 international land station reports every 6 hours, 200 ship reports every 6 hours, 500 aircraft in-flight reports each day, 300 aircraft reconnaissance reports each day, 500 winds aloft reports every 6 hours, and 300 radiosonde reports every 12 hours. From these reports, the necessary maps are prepared and transmitted by facsimile machine to National Weather Service, Air Force and Navy weather stations, and FAA Flight Service Stations. The same data that is printed in black and white by the facsimile receiver is also transmitted in code form by teletype circuits. Maps can be drawn by local weather station personnel using the coded data if some malfunction occurs in the facsimile equipment or if facsimile receivers are not available at the station. The facsimile form of the map for North America shows the 48 conterminous states and parts of Canada and Mexico with small portions of the North Atlantic and North Pacific Oceans.

Note: Some facsimile receivers print the facsimile maps in brown and white.

12-2. The Surface Analysis

The surface analysis (also called surface synoptic chart) provides a map-oriented picture of the weather as it exists at the time of observation (fig 12-1). This picture includes the atmospheric pressure patterns at the surface (pressure systems), fronts, and individual reporting station data.

a. Construction. Facsimile synoptic maps are drawn at the NMC eight times each day. The observations for these maps are taken at 0000Z, 0300Z, 0600Z, 0900Z, 1200Z, 1500Z, 1800Z, and 2100Z. The time of the observation appears in the lower left cor-

ner of the map. These observations are encoded and transmitted to the NMC by radio, telephone, and teletype. At the NMC this data is decoded, and the master map is drawn for facsimile transmission to the using agencies. The map is drawn to a 1:10,000,000 scale and shows a great number of stations, over the North American area. The transmission of the facsimile surface maps is usually completed 1½ to 2 hours after the time of observation. The data on the facsimile surface map is, therefore, generally between 2 and 5 hours old when used by the aviator in the weather station. However, this facility shows the most complete picture of weather conditions over the entire United States. (The teletype sequence report is designed to provide up-to-the-minute individual station weather information.) The 0000Z, 0600Z, 1200Z, and 1800Z maps are also drawn to a 1:20,000,000 scale and depict fewer stations over a larger area. All of the symbols appearing on these maps are black when transmitted since the facsimile machine cannot reproduce color transmissions. At most weather stations, the major features of these maps are colored by the weather personnel on duty. A sequence of three or four maps is displayed in the weather office to indicate trends in the development of fronts, pressure systems, and weather phenomena.

Note: A few weather stations provide a locally prepared sectional surface analysis where they feel it is justified. This practice is not too common today since the facsimile maps with local coloring normally fulfill the requirements.

b. Station Model. Data observed by individual stations are plotted in the form of standard symbols on the surface weather map. These symbols are grouped around a printed circle called the *station circle*, which indicates the geographical location of the station on the chart (fig 12-2). This grouping of data is the *station model*. The arrangement of plotted data around the station model is standard in weather stations throughout the world. On NMC facsimile maps, the abbreviated station model includes only the sky cover, surface wind, present weather, temperature, dew point, cloud types, pressure, pressure tendency, and accumulated precipitation.

(1) *Wind.* The direction from which the wind is blowing is indicated on the surface weather map by a

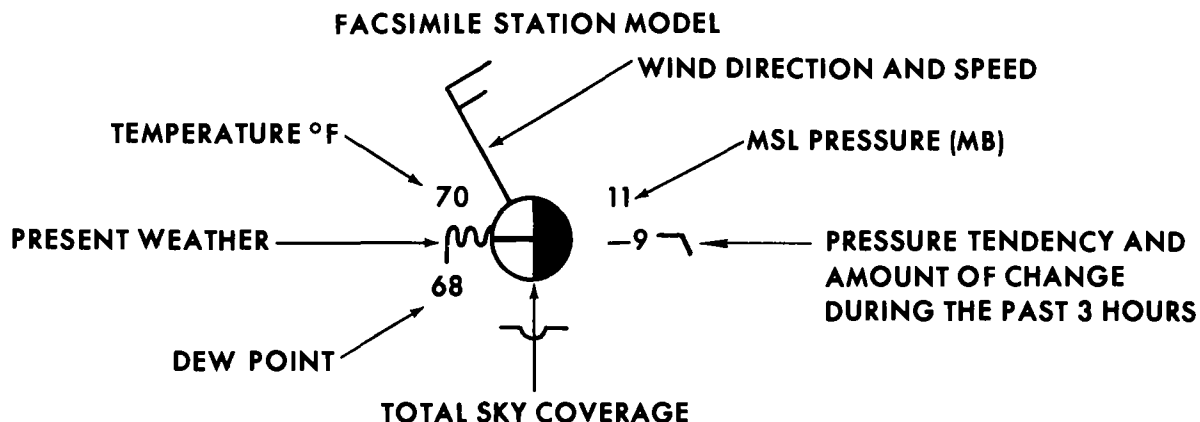


Figure 12-2. Facsimile station model.

shaft. The shaft on the station models in figure 12-2 indicates wind from the northwest. Wind speed is indicated by the barb and pennant system—a full barb is valued at 10 knots, a half-barb at 5 knots, and a pennant at 50 knots. To avoid confusion in length with a single full barb, the half-barb appears part way down the shaft when 5-knot winds exist. The wind speed is a summation of the number of barbs and pennants appearing on the shaft. For a calm wind, a circle is drawn around the station center. The wind direction is determined by reference to true north (a *true wind*), and the speed is rounded to the nearest 5 knots.

(2) *Sky coverage.* The amount of black in the facsimile station circle is an indication of the total amount of sky coverage by all cloud layers over the station (fig 12-2 and 12-3). These symbols are part of the international surface synoptic code.

(3) *Pressure.* The mean sea level pressure is indicated to the nearest millibar (two digits). If the reported pressure begins with a digit from 0 through 5, the figure is preceded with a 10; i.e., 09 means 1009 millibars, and 33 means 1033 millibars. When the reported pressure begins with a digit from 6 through 9, the figure is preceded with a 9; i.e., 99 means 999 millibars, and 65 means 965 millibars. These pressure values are corrected to mean sea level to eliminate pressure variations caused by varying field elevations.

(4) *Temperature and dew point.* On surface weather maps, prepared by United States weather services, the temperatures and dew points are given in degrees Fahrenheit. However, weather maps produced in most other major countries give the temperatures and dew points in the centigrade scale.

(5) *Present weather.* The symbols used for present weather (fig 12-3 and 12-4) represent forms of precipitation or obstructions to vision, or both. Although there are 100 possible combinations and types

of weather symbols (fig 12-4), the aviator needs to recognize only the major types (fig 12-3).

(6) *Visibility.* Visibility in statute miles is normally plotted only on the sectional map. Both whole and fractional parts of miles are shown, as applicable.

(7) *Pressure tendency.* Pressure tendency changes over the past 3 hours are indicated as follows: a plus or minus indicates whether the net change in pressure has resulted in an increase or a decrease; the amount of change is indicated in tenths of millibars; and the pattern of change is indicated by the coded symbol (fig 12-3).

(8) *Cloud types.* Although there are 27 cloud types symbolized in the international code, a knowledge of the 10 basic types (fig 12-3) will provide the aviator with a practical understanding of those symbols used. The same symbol (plotted above the station circle) is used for either nimbostratus or thick altostratus clouds. These two cloud types are similar in that both may obscure the sun and produce continuous precipitation at the surface. Cloud types are generally plotted for all stations on sectional maps and on the facsimile map.

c. *Weather Map Analysis.* Station models are used by the National Meteorological Center (NMC) and local weather station personnel to analyze the surface weather map. The meteorologist draws the pressure patterns by using the wind data and sea level pressure. Isobars show the general pressure pattern and low-level circulation (below approximately 3,000 feet). The location of fronts is determined by using the dew point, temperature, wind, pressure tendencies, clouds, and present weather.

(1) *Isobars.* Isobars are drawn at 4-millibar intervals on maps of North America. This interval places the isobars close enough to show the pressure pattern, but leaves sufficient space to plot additional data legibly. The isobars are labeled in tens of millibars by multiples of four, i.e., labeled 92, 96, 00, 04,

SKY CONDITION	PRESENT WEATHER		PRESSURE TENDENCY	CLOUDS
 CLEAR	 RAIN	 RAIN SHOWER	 RISING, THEN FALLING	 St
 1/10 OR LESS	 DRIZZLE		 RISING AND STEADY	 Sc
 2/10 TO 3/10	 SNOW	 SQUALL	 RISING	 Nb
 4/10	 ICE PELLETS	 FUNNEL CLOUD	 FALLING, THEN RISING	 Ci
 5/10	 HAIL	 BLOWING SNOW	 STEADY	 Cb
 6/10	 THUNDERSTORM	 FOG	 FALLING, THEN RISING	 Ac
 7/10 TO 8/10	 FREEZING DRIZZLE	 BLOWING DUST OR SAND	 FALLING, THEN STEADY	 As (THIN)
 9/10	 FREEZING RAIN	 DUST DEVIL	 FALLING	 Ci
 COMPLETE OVERCAST	 SNOW SHOWER	 SMOKE	 RISING, THEN FALLING	 Ci
 OBSCURATION	 THUNDERSTORM AND RAIN	 HAZE		 Ci

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Figure 12-8. Major station model symbols.

00  CLOUD DEVELOPMENT NOT DISCOVERED OR NOT OBSERVABLE DURING PAST HOUR	01  CLOUDS GENERALLY DISSIPATING OR DECOM- ING LESS DEVELOPING DURING PAST HOUR	02  STATE OF SKY ON THE WHOLE UNCHANGED DURING PAST HOUR	03  CLOUDS GENERALLY FORMING OR DEVELOP- ING DURING PAST HOUR	04  VISIBILITY REDUCED BY SMOKE	05  DRY HAZE.	06  WIDESPREAD DUST IN SUSPENSION IN THE AIR, NOT RAISED BY WIND, AT TIME OF OBSERVATION	07  DUST OR SAND RAISED BY WIND AT TIME OF OB
10  LIGHT FOG.	11  PATCHES OF SHALLOW FOG AT STATION, NOT DEEPER THAN 6 FEET ON LAND	12  MORE OR LESS CONTIN- UOUS SHALLOW FOG AT STATION, NOT DEEPER THAN 6 FEET ON LAND	13  LIGHTNING VISIBLE.	14  PRECIPITATION WITHIN SIGHT, BUT NOT REACH- ING THE GROUND AT STATION	15  PRECIPITATION WITHIN SIGHT, REACHING THE GROUND, BUT DISTANT FROM STATION	16  PRECIPITATION WITHIN SIGHT, REACHING THE GROUND, NEAR TO BUT NOT AT STATION	17  THUNDER HEARD, BUT NO PRECIPITATION AT THE STATION
20  DRIZZLE (NOT FREEZ- ING AND NOT FALLING AS SHOWERS) DURING PAST HOUR, BUT NOT AT TIME OF OB	21  RAIN (NOT FREEZING AND NOT FALLING AS SHOWERS) DURING PAST HOUR, BUT NOT AT TIME OF OB	22  SNOW (NOT FALLING AS SHOWERS) DURING PAST HOUR, BUT NOT AT TIME OF OB	23  RAIN AND SNOW (NOT FALLING AS SHOWERS) DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	24  FREEZING DRIZZLE OR FREEZING RAIN (NOT FALLING AS SHOWERS) DURING PAST HOUR, BUT NOT AT TIME OF OBSERVA- TION	25  SHOWERS OF RAIN DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	26  SHOWERS OF SNOW, OR OF RAIN AND SNOW, DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	27  SHOWERS OF HAIL, OR OF HAIL AND RAIN, DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION
30  SLIGHT OR MODERATE DUST STORM OR SAND- STORM, HAS DECREASED DURING PAST HOUR	31  SLIGHT OR MODERATE DUST STORM OR SAND- STORM, NO APPRECI- ABLE CHANGE DURING PAST HOUR	32  SLIGHT OR MODERATE DUST STORM OR SAND- STORM, HAS INCREASED DURING PAST HOUR	33  SEVERE DUST STORM OR SANDSTORM, NO APPRECIABLE CHANGE DURING PAST HOUR	34  SEVERE DUST STORM OR SANDSTORM, NO APPRECIABLE CHANGE DURING PAST HOUR	35  SEVERE DUST STORM OR SANDSTORM, HAS INCREASED DURING PAST HOUR	36  SLIGHT OR MODERATE DRIFTING SNOW, GENER- ALLY LOW	37  HEAVY DRIFTING SNOW, GENERALLY LOW
40  FOG AT DISTANCE AT TIME OF OB, BUT NOT AT STATION DURING PAST HOUR	41  FOG IN PATCHES	42  FOG, SKY DISCERNIBLE HAS BECOME THINNER DURING PAST HOUR	43  FOG, SKY NOT DISCERN- IBLE, HAS BECOME THINNER DURING PAST HOUR	44  FOG, SKY DISCERNIBLE NO APPRECIABLE CHANGE DURING PAST HOUR	45  FOG, SKY NOT DISCERN- IBLE, NO APPRECIABLE CHANGE DURING PAST HOUR	46  FOG, SKY DISCERNIBLE, HAS BEGUN OR BECOME THICKER DURING PAST HOUR	47  FOG, SKY NOT DISCERN- IBLE, HAS BEGUN OR BECOME THICKER DURING PAST HOUR
50  INTERMITTENT DRIZ- ZLE (NOT FREEZING) SLIGHT AT TIME OF OBSERVATION	51  CONTINUOUS DRIZZLE (NOT FREEZING) SLIGHT AT TIME OF OBSERVA- TION	52  INTERMITTENT DRIZ- ZLE (NOT FREEZING) MODERATE AT TIME OF OBSERVATION	53  CONTINUOUS DRIZZLE (NOT FREEZING) MOD- ERATE AT TIME OF OB	54  INTERMITTENT DRIZ- ZLE (NOT FREEZING), THICK AT TIME OF OBSERVATION	55  CONTINUOUS DRIZZLE (NOT FREEZING) THICK AT TIME OF OBSERVA- TION	56  SLIGHT FREEZING DRIZZLE.	57  MODERATE OR THICK FREEZING DRIZZLE
60  INTERMITTENT RAIN (NOT FREEZING) SLIGHT AT TIME OF OBSERVA- TION	61  CONTINUOUS RAIN (NOT FREEZING) SLIGHT AT TIME OF OBSERVA- TION	62  INTERMITTENT RAIN (NOT FREEZING) MOD- ERATE AT TIME OF OB	63  CONTINUOUS RAIN (NOT FREEZING) MOD- ERATE AT TIME OF OBSERVATION	64  INTERMITTENT RAIN (NOT FREEZING), HEAVY AT TIME OF OBSERVATION	65  CONTINUOUS RAIN (NOT FREEZING), HEAVY AT TIME OF OBSERVATION	66  SLIGHT FREEZING RAIN	67  MODERATE OR HEAVY FREEZING RAIN
70  INTERMITTENT FALL OF SNOW FLAKES, SLIGHT AT TIME OF OBSERVA- TION	71  CONTINUOUS FALL OF SNOW FLAKES, SLIGHT AT TIME OF OBSERVA- TION	72  INTERMITTENT FALL OF SNOW FLAKES, MOD- ERATE AT TIME OF OBSERVATION	73  CONTINUOUS FALL OF SNOW FLAKES, MOD- ERATE AT TIME OF OBSERVATION	74  INTERMITTENT FALL OF SNOW FLAKES HEAVY AT TIME OF OBSERVATION	75  CONTINUOUS FALL OF SNOW FLAKES, HEAVY AT TIME OF OBSERVA- TION	76  ICE PELLS (WITH OR WITHOUT FOG)	77  HEAVY ICE PELLS (WITH OR WITHOUT FOG)
80  SLIGHT RAIN (SHOWERS)	81  MODERATE OR HEAVY RAIN (SHOWERS)	82  VIOLENT RAIN (SHOW- ERS)	83  SLIGHT SHOWER(S) OF RAIN AND SNOW MIXED	84  MODERATE OR HEAVY SHOWER(S) OF RAIN AND SNOW MIXED	85  SLIGHT SNOW SHOWERS	86  MODERATE OR HEAVY SNOW SHOWERS	87  SLIGHT SHOWER(S) OF SOFT OR SMALL HAIL WITH OR WITHOUT RAIN OR RAIN AND SNOW MIXED
90  MODERATE OR HEAVY SHOWER(S) OF HAIL WITH OR WITHOUT RAIN OR RAIN AND SNOW MIX- ED, NOT APPRECIABLE CHANGE DURING PAST HOUR	91  SLIGHT RAIN AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	92  MODERATE OR HEAVY RAIN AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	93  SLIGHT SNOW OR RAIN AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	94  MODERATE OR HEAVY SNOW OR RAIN AND SNOW MIXED AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	95  SLIGHT SNOW OR RAIN AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	96  SLIGHT SNOW OR RAIN AT TIME OF OB, THUNDER HEARD DURING PAST HOUR, BUT NOT AT TIME OF OBSERVATION	97  HEAVY THUNDER STORM WITH HAIL, BUT NOT WITH RAIN AND SNOW AT TIME OF OBSERVATION

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Figure 12-4. Symbols used on weather maps.

CLOUDS OF TYPE C _L		CLOUDS OF TYPE C _M		CLOUDS OF TYPE C _H		PAST WEATHER	TOTAL AMOUNT ALL CLOUDS	BAROMETER CHARACTERISTIC	
08		09		0		0		0	
WELL DEVELOPED DUST DEVIL(S) WITHIN PAST HR		DUST STORM OR SAND STORM WITHIN SIGHT OF OR AT STATION DURING PAST HOUR		NO SC, ST, CU, OR CB CLOUDS.		NO AC, AS OR NS CLOUDS.		NO CI, CC, OR CS CLOUDS.	
CLEAR OR FEW CLOUDS.		NO CLOUDS.							
18		19		1		1		1	
SQUALL(S) WITHIN SIGHT DURING PAST HOUR.		FUNNEL CLOUD(S) WITHIN SIGHT DURING PAST HOUR.		CU WITH LITTLE VERTICAL DEVELOPMENT AND SEEMINGLY FLATTENED		THIN AS ENTIRE CLOUD LAYER SEMI-TRANSPARENT		FILAMENTS OF CI SCATTERED AND NOT INCREASING.	
PARTLY CLOUDY (SCATTERED) OR VARIABLE SKY.		LESS THAN ONE-TENTH OR ONE-TENTH.							
28		29		2		2		2	
FOG DURING PAST HOUR, BUT NOT AT TIME OF OBS.		THUNDERSTORM (WITH OR WITHOUT PRECIPITATION) DURING PAST HOUR, BUT NOT AT TIME OF OBS.		CU OF CONSIDERABLE DEVELOPMENT, GENERALLY TOWERING, WITH OR WITHOUT OTHER CU OR SC BASES ALL AT SAME LEVEL.		THICK AS, OR NS.		DENSE CI IN PATCHES OR TWISTED SHEAVES, USUALLY NOT INCREASING.	
CLOUDY (BROKEN) OR OVERCAST									
38		39		3		3		3	
SLIGHT OR MODERATE DRIFTING SNOW, GENERALLY HIGH		HEAVY DRIFTING SNOW, GENERALLY HIGH		CB WITH TOPS LACKING CLEAR-CUT OUTLINES, BUT DISTINCTLY NOT CIRRIFORM OR ANVIL-SHAPED; WITH OR WITHOUT CU, SC, OR ST		THIN AC; CLOUD ELEMENTS NOT CHANGING MUCH AND AT A SINGLE LEVEL.		CI OFTEN ANVIL-SHAPED, DERIVED FROM OR ASSOCIATED WITH CB	
SANDSTORM, OR DUST-STORM, OR DRIFTING OR SLOWING SNOW									
48		49		4		4		4	
FOG DEPOSITING RIME, SKY DISCERNIBLE.		FOG, DEPOSITING RIME, SKY NOT DISCERNIBLE.		SC FORMED BY SPREADING OUT OF CU; CU OFTEN PRESENT ALSO		THIN AC IN PATCHES; CLOUD ELEMENTS CONTINUALLY CHANGING AND/OR OCCURRING AT MORE THAN ONE LEVEL.		CI, OFTEN HOOK-SHAPED, GRADUALLY SPREADING OVER THE SKY AND USUALLY THICKENING AS A WHOLE.	
FOG, OR SMOKE, OR THICK DUST HAZE									
58		59		5		5		5	
RAIN OR DRIZZLE AND SNOW, SLIGHT.		ORRIZLE AND RAIN, MODERATE OR HEAVY.		SC NOT FORMED BY SPREADING OUT OF CU.		THIN AC IN BANDS OR IN A LAYER GRADUALLY SPREADING OVER SKY AND USUALLY THICKENING AS A WHOLE.		CI AND CS, OFTEN IN CONVERGING BANDS, OR CS ALONE, THE CONTINUOUS LAYER NOT REACHING 45° ALTITUDE.	
RAIN									
68		69		6		6		6	
RAIN OR DRIZZLE AND SNOW, MODERATE OR HEAVY		RAIN OR DRIZZLE AND SNOW, MODERATE OR HEAVY		ST OR FS OR BOTH, BUT NOT FS OF BAD WEATHER.		AC FORMED BY THE SPREADING OUT OF CU		CI AND CS, OFTEN IN CONVERGING BANDS, OR CS ALONE, THE CONTINUOUS LAYER NOT REACHING 45° ALTITUDE.	
RAIN									
78		79		7		7		7	
ISOLATED STARLIKE SNOW CRYSTALS (WITH OR WITHOUT FOG)		ICE PELLETS (SLEET, U.S. DEFINITION)		FS AND/OR FC OF BAD WEATHER (SCUDS) USUALLY UNDER AS AND NS		DOUBLE-LAYERED AC OR A THICK LAYER OF AC, NOT INCREASING OR AS AND AC BOTH PRESENT AT SAME OR DIFFERENT LEVELS.		CS COVERING THE ENTIRE SKY	
SNOW, OR RAIN AND SNOW MIXED, OR ICE PELLETS (SLEET)									
88		89		8		8		8	
MODERATE OR HEAVY SHOWER(S) OF RAIN, WITH OR WITHOUT SMALL HAIL, WITH OR WITHOUT RAIN OR SNOW MIXED, NOT ASSOCIATED WITH THUNDER		SLIGHT SHOWER(S) OF RAIN, WITH OR WITHOUT RAIN OR SNOW MIXED, NOT ASSOCIATED WITH THUNDER		CU AND SC NOT FORMED BY SPREADING OUT OF CU WITH BASES AT DIFFERENT LEVELS		AC IN THE FORM OF CU-SHAPED TUFTS OR AC WITH TURRETS		CS NOT INCREASING AND NOT COVERING ENTIRE SKY, CI AND CC MAY BE PRESENT	
SHOWER(S)									
98		99		9		9		9	
THUNDERSTORM COMBINED WITH DUST STORM AT TIME OF OBSERVATION.		HEAVY THUNDERSTORM WITH HAIL, AT TIME OF OBS.		CB HAVING A CLEARLY FIBROUS (CIRRIFORM) TOP, OFTEN ANVIL-SHAPED, WITH OR WITHOUT CU, SC, ST, OR SCUD.		AC OF A CHAOTIC SKY, USUALLY AT DIFFERENT LEVELS; PATCHES OF DENSE CI ARE USUALLY PRESENT ALSO		CC ALONE OR CC WITH SOME CI OR CS, BUT THE CC BEING THE MAIN CIRRIFORM CLOUD PRESENT	
THUNDERSTORM, WITH OR WITHOUT PRECIPITATION									
SKY OBSCURED.									

Figure 12-4—Continued.

aavn223

TYPE	SYMBOLIZED LINE (FACSIMILE)	COLOR (SECTIONAL)
COLD FRONT		
WARM FRONT		
OCCCLUDED FRONT		
STATIONARY FRONT		
UPPER COLD FRONT		
SQUALL LINE		
TROUGH LINE		
RIDGE LINE		

aavn224

Figure 12-5. Weather map analysis symbols.

and 08 would be interpreted as 992 millibars, 996 millibars, 1,000 millibars, 1,004 millibars, and 1,008 millibars. The 1,016-millibar line is the *normal* boundary between cyclones and anticyclones.

(2) *Isobaric patterns.* The pattern formed by the isobars shows the flow of the gradient wind above the effect of surface friction. At approximately 2,000 feet (the gradient level), winds flow parallel to the isobars; below the gradient level, winds tend to flow toward the lower pressure area. The average angle at which the surface winds cross the isobars is approximately 30° over a normal land surface; the angle is less over water and greater over irregular surfaces. The actual wind direction below 2,000 feet should be obtained from the station models. On surface weather maps of the United States, the windflow is counter-clockwise around cyclones and clockwise around anticyclones. Cyclones are typically areas of overcast sky, turbulence, and generally unfavorable flying conditions. Cyclonic centers are characterized by gusty, strong, erratic winds, as opposed to anticyclone centers of calm or light and variable winds. A high typically represents an area of clear sky, smooth air at flight level, and generally good weather. Centers of high and low pressure are labeled with a blue H or a red L on display maps.

(3) *Isobaric spacing.* Closely spaced isobars indicate a strong pressure gradient, while widely spaced isobars indicate a weak pressure gradient. Therefore, the winds along the same latitude are strong where isobars are closely spaced and weak where the isobaric spacing is wide. Isobars are usually closely spaced around low-pressure centers and widely spaced around high-pressure centers.

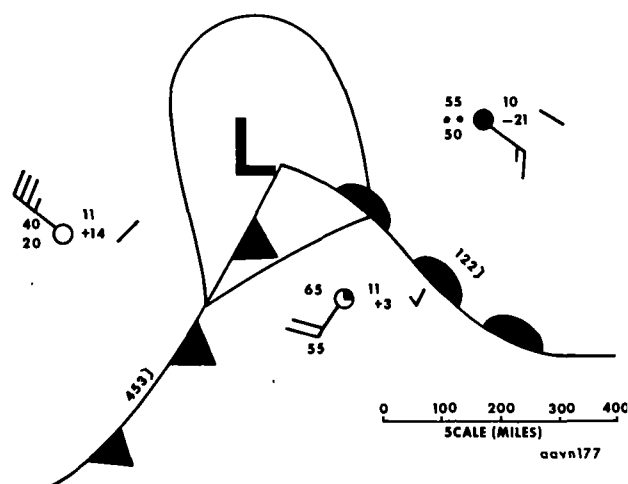
d. Weather Map Analysis Symbols.

(1) *Frontal symbols.* Fronts are indicated on facsimile surface weather maps by symbolized lines (fig 12-5). On locally prepared sectional maps or locally colored facsimile maps, these fronts are indicated by colored lines. Prefrontal squall lines and trough lines are also symbolized or colored (fig 12-5). The spacing between the symbols on the lines is subject to considerable variation. A coded analysis (fig 12-6) of the front is plotted with a bracket along the front on the facsimile surface weather map.

(2) *Areas of weather and restricted visibility.* When a certain type of weather or restriction to visibility is indicated at given stations over a rather large area on the map, a large symbol corresponding to the symbol used for present weather on the station model (fig 12-3) is drawn in color on the map at the local weather station. If a large area of precipitation or restriction to visibility is present, the entire area is colored for immediate identification. Colors are as follows:

- Areas of continuous precipitation—solid green shading.
- Areas of intermittent precipitation—green hatching.
- Areas of fog—solid yellow shading.
- Areas of blowing dust or sand—solid brown shading.
- Hazardous weather—appropriate station model symbol in red.
- Showers—appropriate symbol over a green triangle.

e. *Pressure System Movement.* The most dependable way to determine the movement of pressure sys-



CODE	
1st Digit—Frontal Type	2d Digit—Frontal Intensity
0—Stationary front	0—No specification
1—Warm front	1—Weak, decreasing (incl. frontolysis)
2—Warm occlusion	2—Weak, little or no change
3—Upper warm front	3—Weak, increasing (incl. frontogenesis)
4—Cold front	4—Moderate, decreasing
5—Cold occlusion	5—Moderate, little or no change
6—Upper cold front	6—Moderate, increasing
7—Squall line	7—Strong, decreasing
8—Intertropical front	8—Strong, little or no change
9—Occlusion	9—Strong, increasing
3d Digit—Frontal Characteristic	INTERPRETATION
0—No specification	4—Cold front
1—Frontal activity area, decreasing	[453] 5—Moderate, little or no change
2—Frontal activity area, little change	3—Frontal activity area, increasing
3—Frontal activity area, increasing	[122] 1—Warm front
4—Intertropical	2—Weak, little or no change
5—Forming or existence suspected	2—Frontal activity area, little change
6—Stationary	
7—With waves	
8—Diffuse	
9—Position doubtful	

aavn1200

Figure 12-6. Frontal analysis code.

tems (and the fronts they contain) is to obtain the information from the forecaster on duty or from surface prognostic maps (para 12-5). Two quick methods that the aviator can use to estimate the future movement of pressure systems are *extrapolation* and *pressure tendency*.

(1) *Extrapolation*. Extrapolation is the process of using past movement of the pressure system to predict future movement. By locating the position of a pressure center on the three earlier surface weather maps, the movement (speed and direction) for the past 9 hours can be seen. This trend can then be projected into the future movement of the system for short periods of time (fig 12-7). The same system can be used for predicting the movement of fronts on the

surface weather map. Actual pressure system and frontal movements during a 12-hour period are depicted in figures 12-8 and 12-9.

(2) *Pressure tendency*. Low-pressure systems tend to move toward the area of rapidly falling pressure, and high-pressure systems move toward the area of rapidly rising pressure. An estimate of the amount and direction of movement of a pressure center is obtained by a combination of the direction and speed of past movement and the path parallel to a line joining the rapidly rising and falling pressure.

(a) Because low-pressure convergence areas contain the greatest flight hazards, the future movement of lows is important to aviators. In using pressure tendencies for predicting a low-pressure movement, the extreme negative and highest positive-pressure tendency within 600 to 700 miles of the low-pressure center are located. A straight line is drawn between these points. The future movement of the center moves parallel to this line, with the low moving toward the negative end of the line.

(b) To determine the speed of motion, a second line is drawn parallel to the first line and passing through the center of the low. The speed of movement can be estimated by adding the tendencies at each end of the line (disregarding the signs) and dividing the sum by four (fig 12-10).

12-3. Radar Summary Chart

Radar summary charts present a map-like picture of those areas having precipitation detected by the various weather radar sites around the country. These charts are prepared each hour by the Radar Analysis and Development Unit (ADUS) of the National Severe Storms Center (NSSC) Kansas City, Missouri. Approximately 16 of these charts are transmitted daily over the facsimile machine network and greatly enhance the weather coverage when used in conjunction with other facsimile charts and teletype information. Complete coverage of these charts will be found in chapter 15.

12-4. Weather Depiction Charts

The weather depiction chart (fig 12-11) is transmitted eight times a day beginning at 0100Z and every 3 hours thereafter. It is designed primarily as a supplement to the surface synoptic map for pilot weather briefing. It is derived from teletype data one hour later than that used to construct the surface analysis (para 12-2), and shows visibility, significant weather, and cloud conditions for selected stations across the United States. The station model is comprised as follows: the total sky coverage is plotted in the station circle; visibility, when restricted to 5 miles or less, and significant weather is recorded to the left of the station circle; and the height of the ceiling or

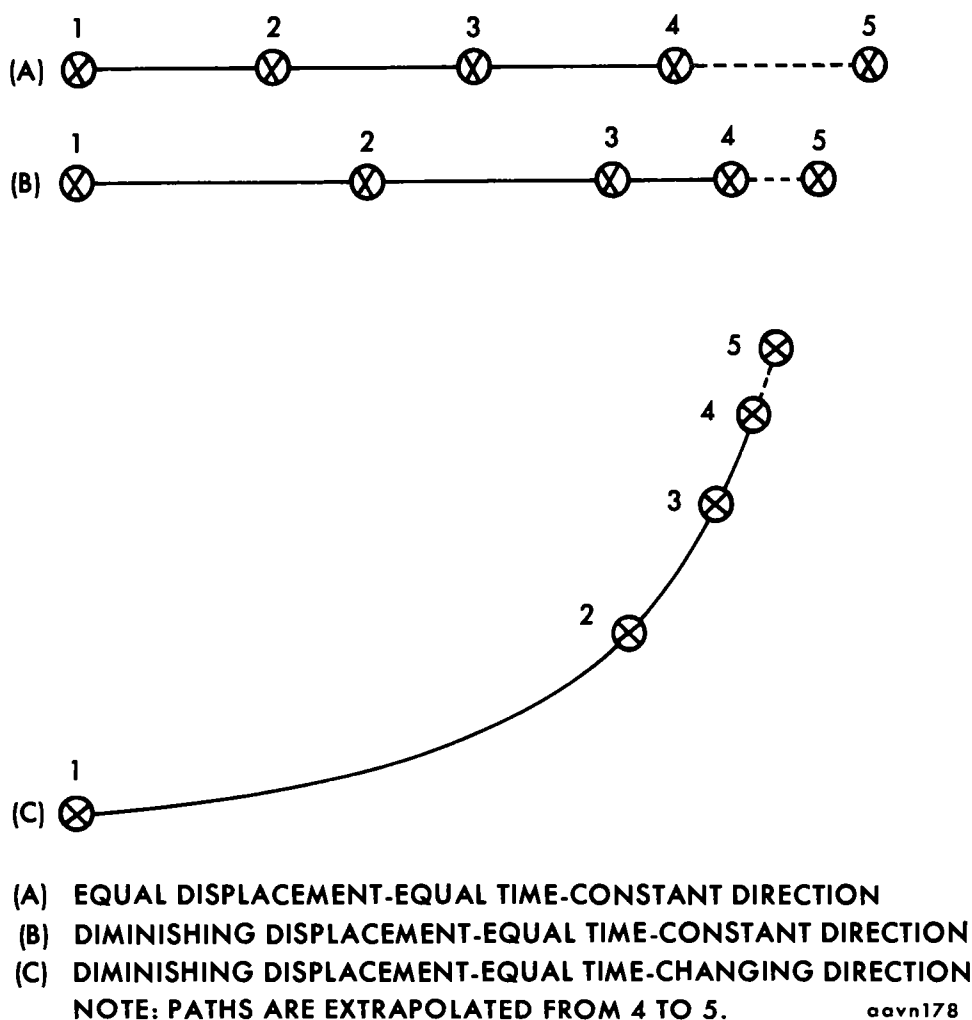


Figure 12-7. Forecasting movement of pressure systems by extrapolation.

the lowest scattered layer is plotted below the station circle in hundreds of feet.

a. IFR Conditions. Areas where the ceiling is less than 1000 feet and/or the visibility is less than 3 miles (fig 12-12) are enclosed by a solid line and will be colored red by the local weather station personnel.

b. MVFR Conditions. Areas where the ceiling is 1000 feet to and including 3000 feet and/or the visibility is 3 miles to and including 5 miles (fig 12-12) are considered *marginal VFR* and will be enclosed by a scalloped line. These areas will be colored blue by local weather station personnel.

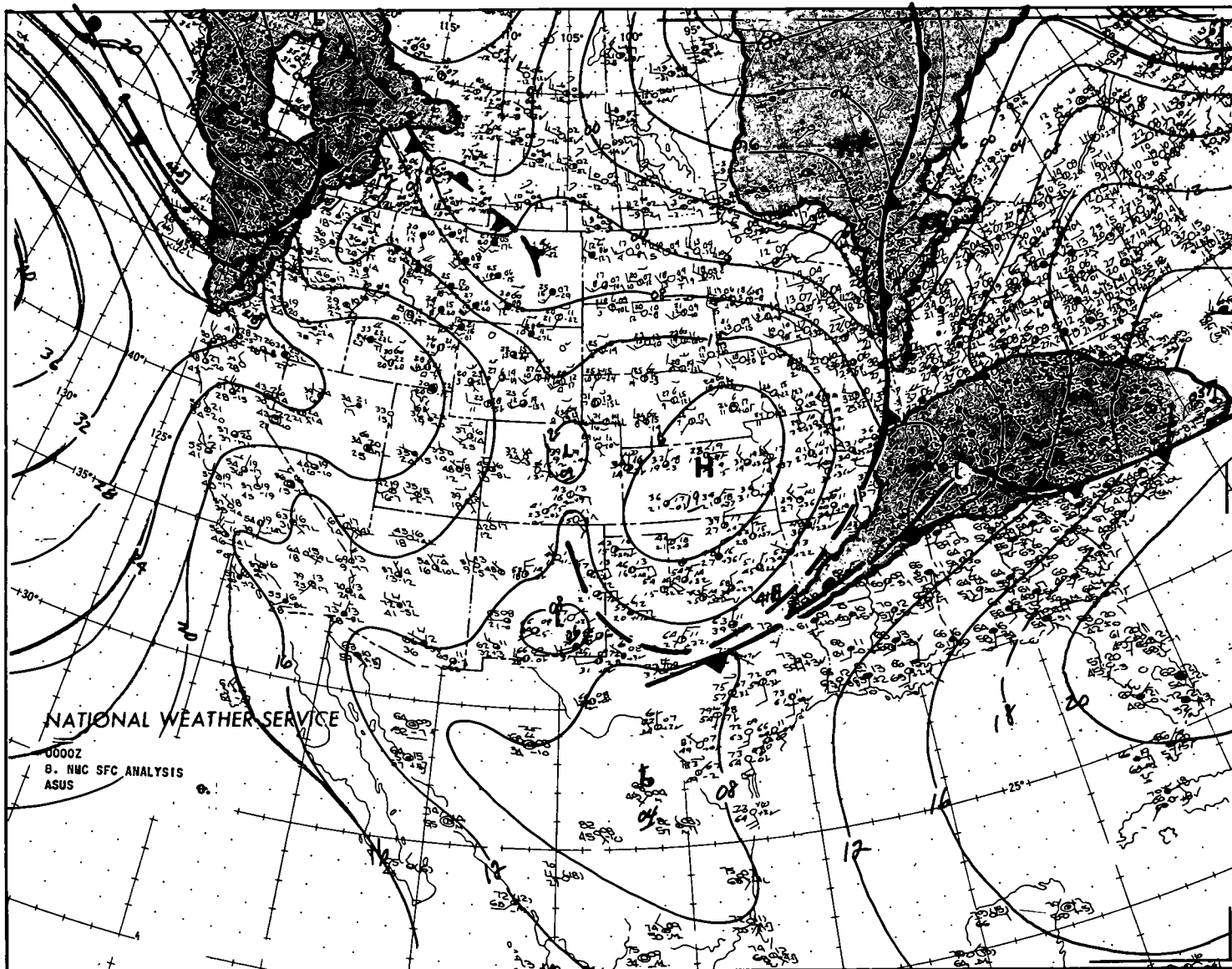
c. VFR Conditions. Remaining areas of the chart (those not encircled by solid or scalloped lines) indicate that ceilings exceed 3000 feet and the visibility exceeds 5 miles.

Note: The above weather criteria as related to IFR, MVFR and VFR conditions is for use as a weather briefing tool. For actual ceiling, visibility and cloud clearance requirements for IFR and VFR flight operations consult FAR, Part 91.

d. Fronts. Frontal locations from the previous hour will be plotted and locally colored to enhance the overall weather depiction (fig 12-11).

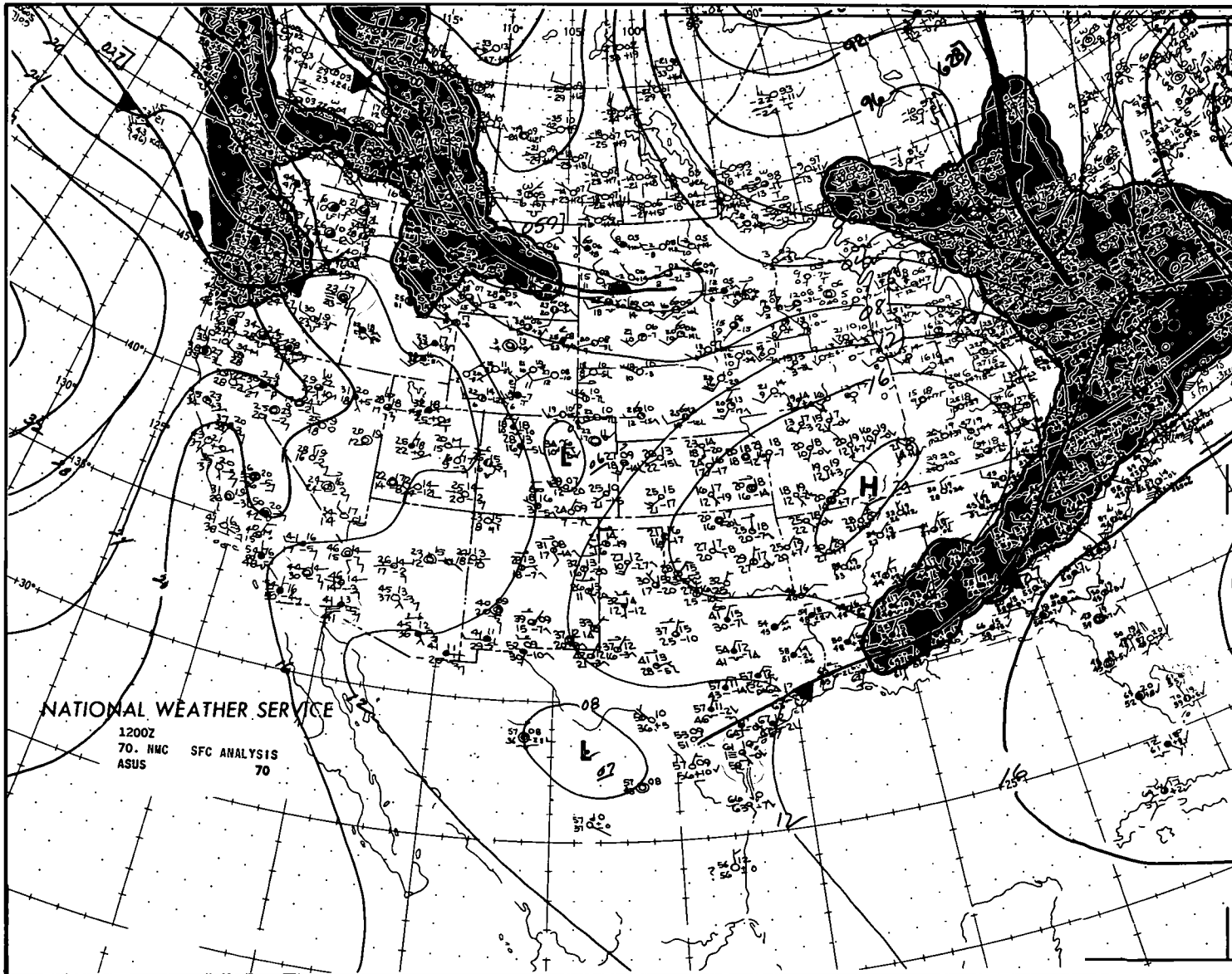
12-5. Significant Weather Prognosis Chart

Twelve- and twenty-four-hour prognostic charts showing significant weather and surface conditions are transmitted four times a day over the facsimile machine circuits. These charts are similar to the weather depiction chart but indicate forecast conditions and include additional data covering turbulence and freezing levels. Complete coverage of this facsimile chart will be found in chapter 16—Forecasts.



aavn1202

Figure 12-8. Surface analysis 0000Z.



aavn1203

Figure 12-9. Surface analysis 1200Z.

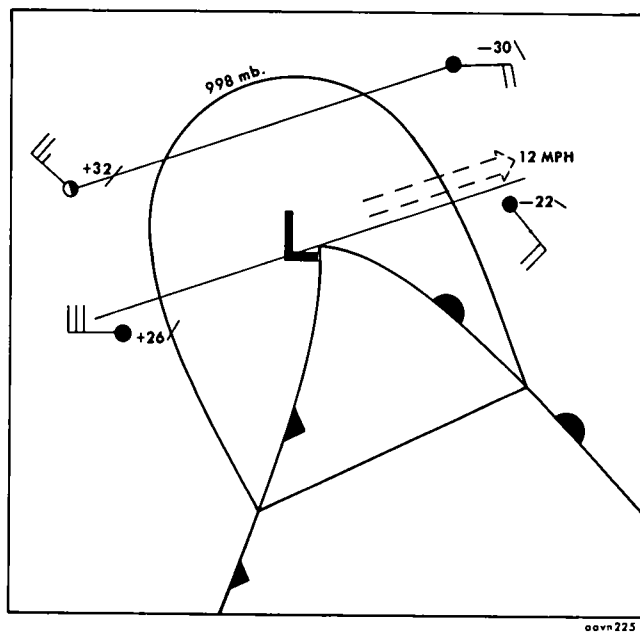


Figure 12-10. Predicting the future movement of a low.



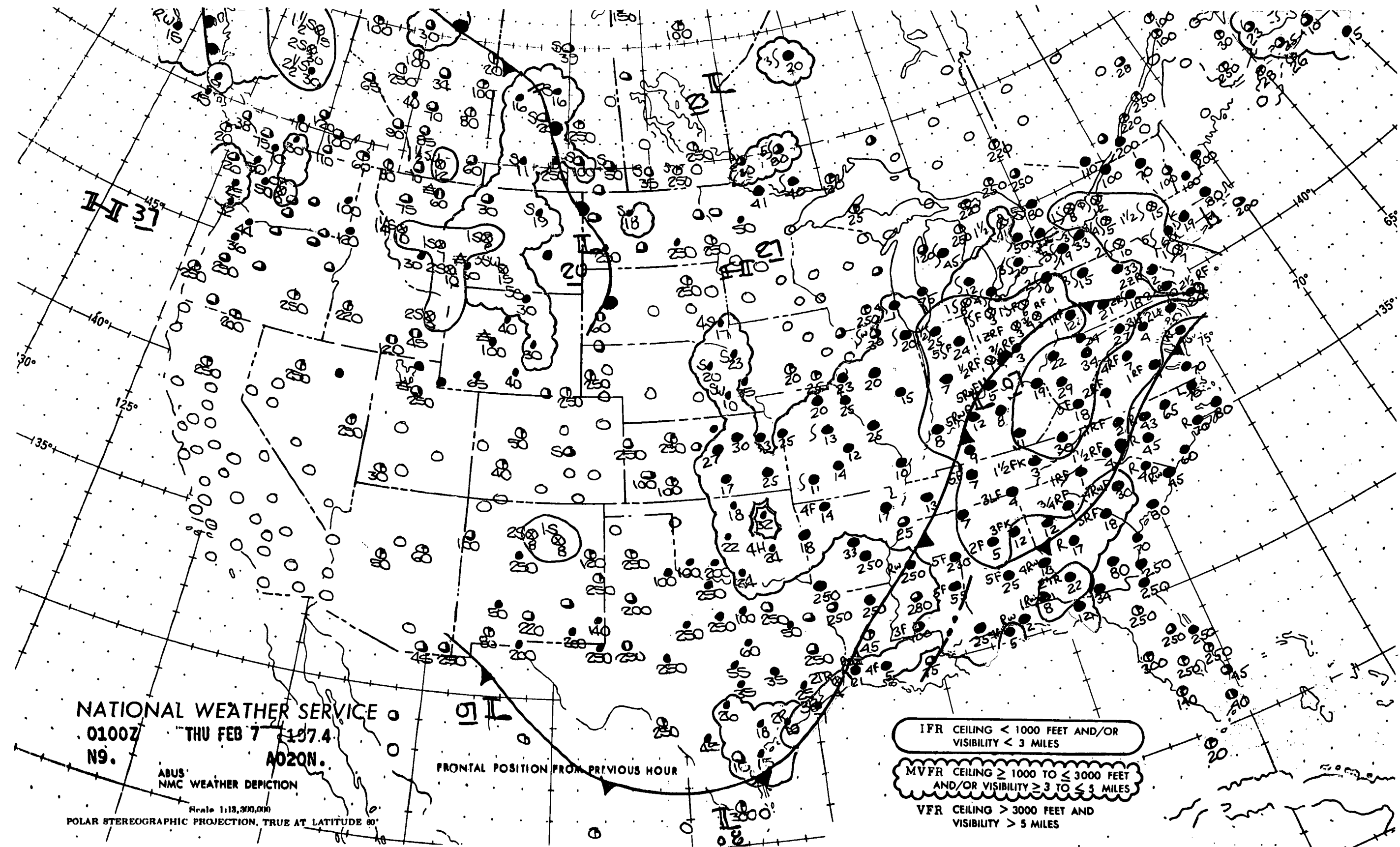


Figure 12-11. Weather depiction chart.

**IFR CEILING < 1000 FEET AND/OR
VISIBILITY < 3 MILES**

**MVFR CEILING $\geq$ 1000 TO $\leq$ 3000 FEET
AND/OR VISIBILITY $\geq$ 3 TO $\leq$ 5 MILES**

**VFR CEILING > 3000 FEET AND
VISIBILITY > 5 MILES**

Figure 12-12. Weather depiction chart legend.



4



4



CHAPTER 13

WINDS ALOFT

13-1. General

Wind is air moving essentially parallel to the earth's surface. Winds aloft vary greatly and are sometimes quite complex. The observed windflow is an important factor in navigation and this information is in great demand by the aviator. The aviator should be able to take advantage of all winds aloft information. The flow of air can affect the groundspeed, thereby affecting the time of arrival and fuel consumption. The flight range is greatly reduced with an adverse windflow.

13-2. Winds Aloft Information

Both current and forecast winds aloft information arrives at the weather office via teletype in code form. It is also received over the facsimile machine in chart form. The code form is more complete, as the charts are prepared only for significant or standard levels. The winds aloft data serves as a basis for preparing winds aloft forecasts and as a tool for pilot briefings.

13-3. Method of Observation

At altitudes above mean sea level, current winds aloft observations are obtained by visual or electronic means.

a. Visual Means. This method is handicapped due to cloud coverage and, at times, distance of the balloon from point of observation. The two visual means of determining winds aloft are pilot balloon (PIBAL) and radiosonde balloon (RABAL).

(1) *PIBAL.* A free balloon, filled with helium so that it has a predetermined ascensional rate, is released and observed with a theodolite. Drafts and turbulence will affect the accuracy. The path that the balloon takes in flight is governed by the direction and speed of the winds through which it ascends. The theodolite is similar to a surveyor's transit and triangular calculations determine the wind direction at each level. At night, a small battery-powered light is attached to the balloon to make it visible. The more experienced the observer the better the results. One advantage of this method is the low cost.

(2) *RABAL.* The winds are obtained in a similar manner as the PIBAL, but the ascensional rate is set by pressure-measuring equipment. This method is more accurate than the PIBAL because there is no assumption made of the ascension rate of the balloon.

In this method the observer visually follows the radio sounding balloon with the theodolite.

b. Electronic Means. Electronic equipment such as radar or radio is used to increase the accuracy of the observation. This also allows wind aloft information to be obtained through layers of clouds and at higher altitudes than otherwise. The two most common electronic means of observing the winds are—

(1) *RAWIN.* Radio or radar is used to obtain the slant range, elevation angle, and azimuth angle to determine the winds aloft.

(2) *RAWINSONDE.* This observation gives a simultaneous measurement of the pressure, temperature, humidity, and winds aloft. This is a combination of RAWIN and radiosonde, using pressure to calculate the altitude.

13-4. Times of Observation

The standard time for upper wind observations are 000Z, 0600Z, 1200Z, and 1800Z. However, delayed releases may be 1 hour later than the above times. PIBAL and scheduled RAWIN are taken every 6 hours. RABAL and RAWINSONDE observations are usually taken only twice daily at 0000Z and 1200Z.

Note. Since current winds aloft codes are complex and not usually posted for the aviator, winds aloft charts and forecast winds are now considered the most important for flight planning. Forecast winds aloft are covered in chapter 16.

13-5. Winds Aloft Charts

a. Method of Plotting. The National Meteorological Center prepares winds aloft charts from the winds aloft reports. These charts are normally transmitted two times daily, approximately 2 hours after the standard PIBAL observation times. The observed winds for appropriate levels are plotted on these charts, using the barb and pennant system (fig 13-1). The wind direction to the nearest 10° is represented by an arrow flowing with the wind and a numeral near the tail of the arrow. A full barb length on the wind arrow represents 10 knots, a half barb 5 knots, and a pennant 50 knots. The wind represented in figure 13-1 is from 280° at 65 knots.

b. Levels Plotted. Winds aloft charts are transmitted over facsimile circuits within the United States.

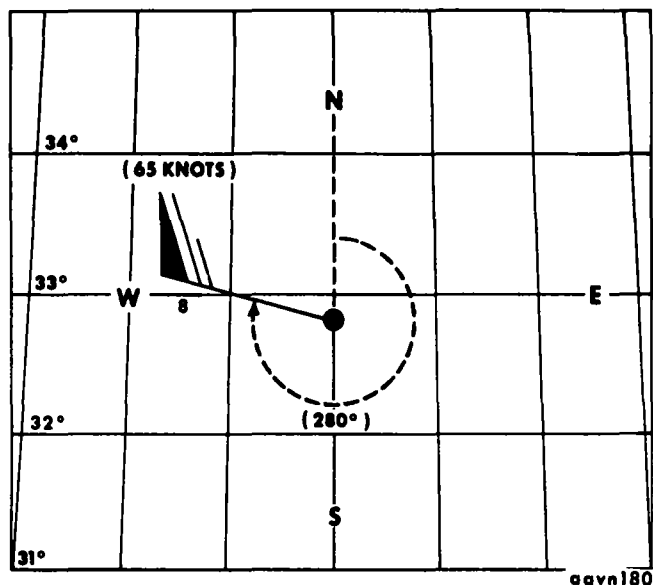


Figure 13-1. Winds aloft chart station model.

There are two winds aloft facsimile charts:

- (1) The lower level chart containing plotted

winds for the second standard level above the surface (approximately 2,000 feet above the ground) 5,000-, 8,000-, and 10,000-foot altitudes above mean sea level (fig 13-2).

- (2) The high level chart containing winds for the 14,000-, 25,000-, 30,000-, and 35,000-foot altitudes above mean sea level (fig 13-3).

Note: Supplementary high altitude wind data may be obtained from the coded teletype winds aloft reports and from constant pressure charts (chap 14).

c. Using the Charts. Winds aloft charts are useful in representing the windflow pattern that existed at the time of the observation. However, the charts are based on observed data several hours old and may not represent the wind that will be encountered on a flight subsequent to the observation time. For this reason, the aviator should also refer to the forecast winds (chap 16) when planning his flight.

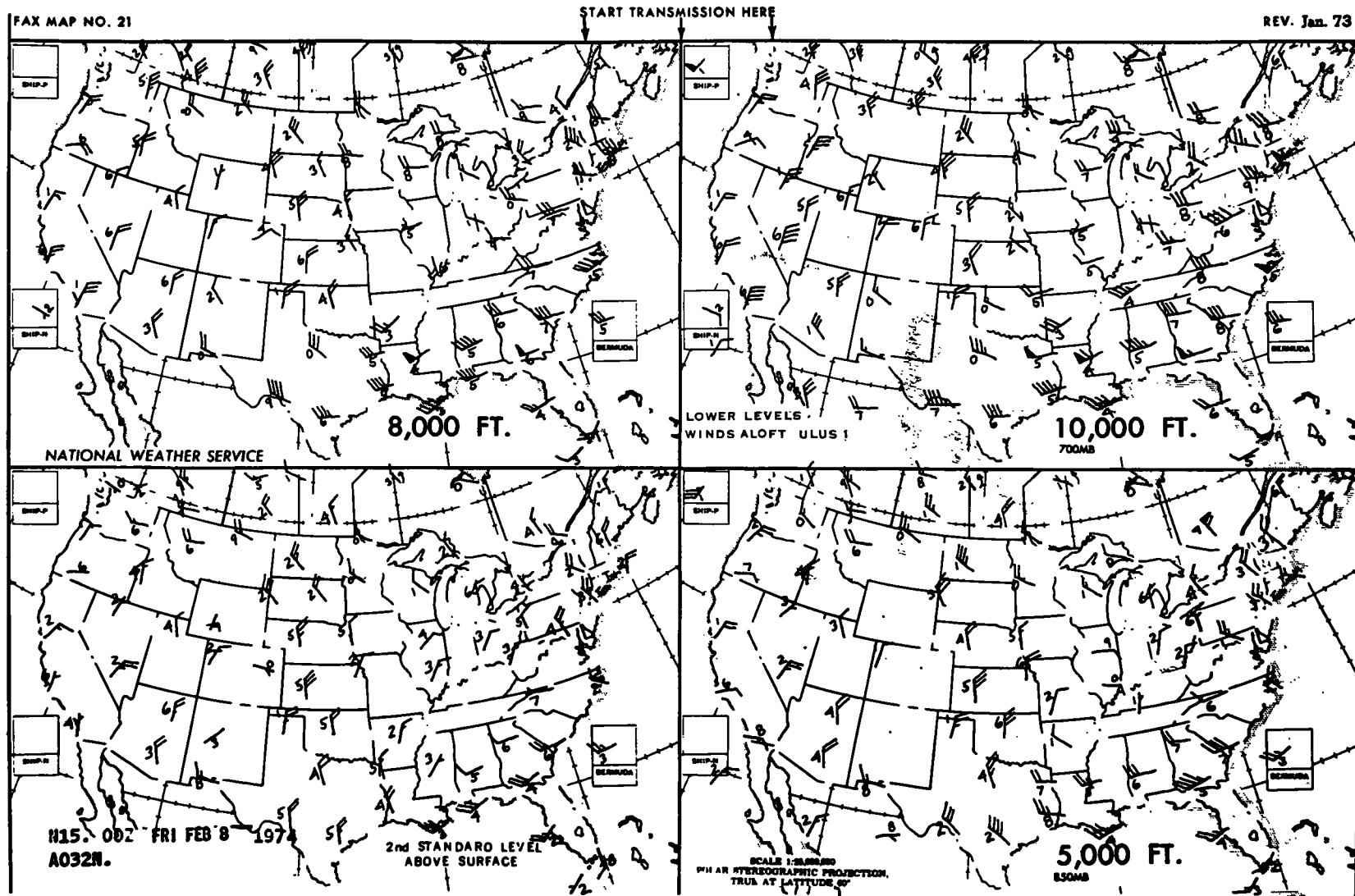


Figure 13-2. Low level winds aloft chart.

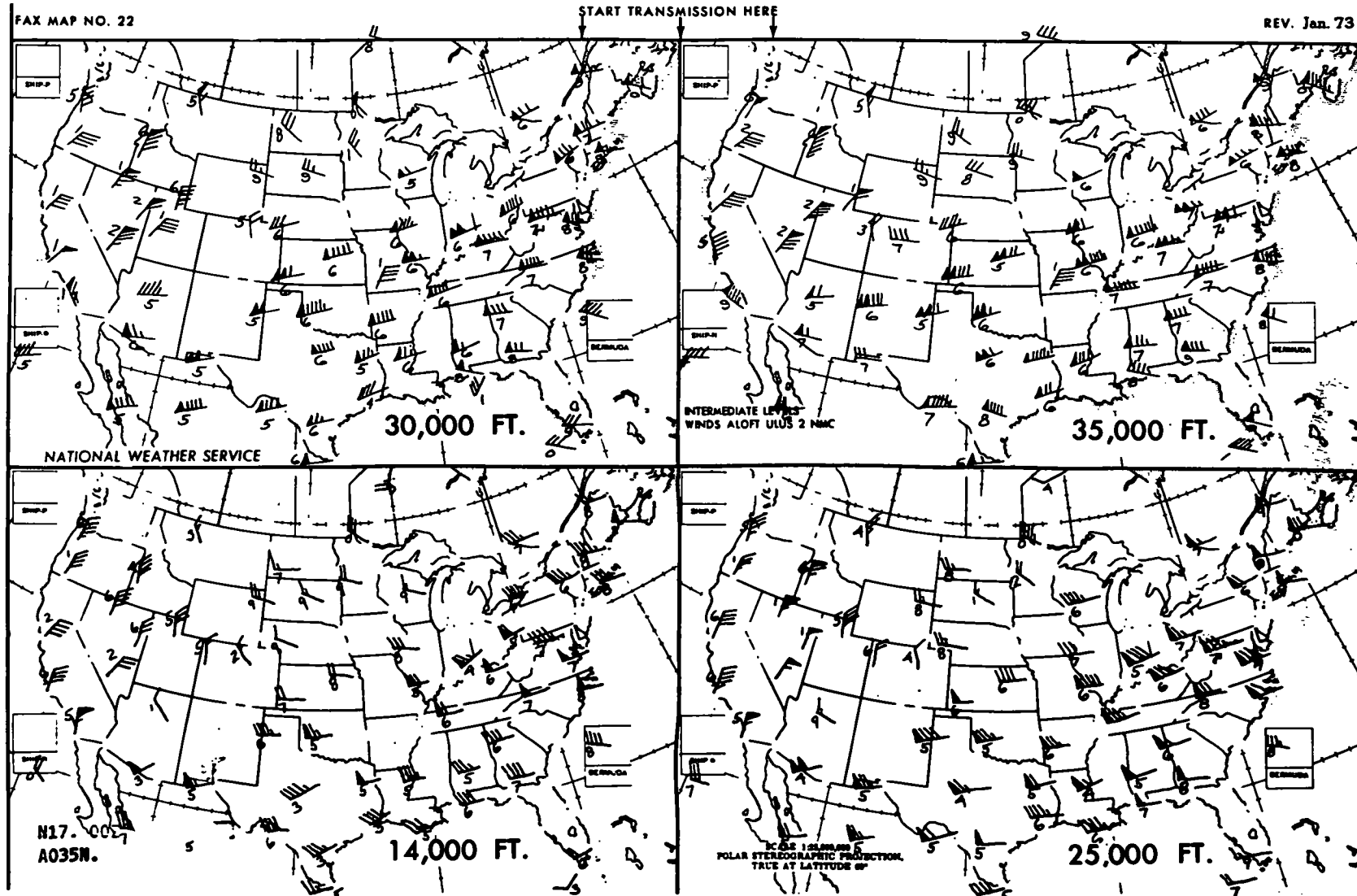


Figure 13-3. High level winds aloft chart.

CHAPTER 14

CONSTANT PRESSURE CHARTS AND HIGH ALTITUDE WEATHER

14-1. General

The surface weather map is effective in presenting pictorially the atmospheric conditions from the surface to approximately 5,000 feet. At altitudes above 5,000 feet, the pressure patterns and frontal positions begin to change shape and location as the surface secondary circulation of migratory cyclones and anticyclones merges gradually into the more constant primary circulation of the upper atmosphere. *Constant pressure charts* (fig 14-1) are weather maps designed for flights at and above 5,000 feet. Constant-pressure charts depict the weather along a specific pressure level, whereas surface weather maps depict the pressure changes at a constant altitude (MSL). Furthermore, many weather phenomena occur at high altitudes which are unique to these levels and do not appear on surface weather maps. When flight missions are to be conducted near the middle and upper portions of the troposphere, it will be necessary for the aviator to use weather charts for upper levels, in addition to the surface weather map. The *constant-pressure charts* correlate several weather facilities in the weather station; i.e., the surface weather map, winds aloft charts, and the Skew T, log p Diagram. The constant-pressure charts for each pressure level are computer analyzed and plotted twice each day from observations made at 0000Z and 1200Z.

14-2. Levels of Constant Pressure Charts

The rate of change of pressure with altitude is controlled by the rate of change of temperature with altitude. *For example*, if the temperature of the air decreases faster than it should, the pressure level of 850 millibars, which would be approximately 5,000 feet in standard atmosphere, may be at 4,600 feet or lower in the cold air. When the temperature lapse rate is less than standard, the 850-millibar level may be 5,400 feet or higher in the warmer than standard air. The heights of a pressure level are also influenced by the variation in sea level pressure. A constant pressure chart for the 850-millibar level depicts the amount of altitude variation of the 850-millibar constant pressure level in the atmosphere. Wherever the pressure level varies 60 meters (approximately 200 feet), a new contour line is drawn (fig 14-1). The same type of chart can be drawn for any pressure level desired. However, the standard levels with which the aviator is concerned are—

a. 850-Millibar Chart. In the standard atmosphere the 850-millibar level is 1,457 meters (4,781 feet). For planning flights at approximately 5,000 feet, this chart is the most useful (fig 14-1).

b. 700-Millibar Chart. In the standard atmosphere the 700-millibar level is 3,012 meters (9,882 feet). This chart is used for planning flights near the 10,000-foot level. It is computer analyzed and plotted.

c. 500-Millibar Chart. In the standard atmosphere the 500-millibar level is 5,574 meters (18,289 feet). This chart is used for flight planning near the 18,000-foot level. At this altitude, the atmospheric pressure decreases to approximately one-half the mean sea level pressure value. It is computer analyzed and plotted.

d. 300-Millibar Chart. In the standard atmosphere the 300-millibar level is 9,164 meters (30,065 feet). Although few flights in Army aircraft are performed at this height, the 300-millibar chart is significant in that the strong winds of the jet stream, the associated wind shear and clear air turbulence, and the tops of thunderstorms will frequently appear at this level. It is also used for the interpolation of temperatures and winds for flights between the 18,000- and 30,000-foot levels. The 300-millibar chart is computer analyzed and plotted.

14-3. Source of Data

Data for plotting constant pressure charts is obtained from radiosonde observation. The radiosonde is a balloon-borne instrument which contains (1) a plastic strip coated with a moisture-sensitive film used to measure the moisture content of the air, (2) a thermistor to measure the temperature of the air at mandatory pressure levels, (3) an aneroid wafer which closes electrical relays as it expands to transmit data at specific intervals as the pressure changes, and (4) an electrical transmitter which radios the data to a surface receiver. The distance between the pressure levels at which the radiosonde transmits data is computed by using the average air density (temperature) through the distance; the speed and direction of the wind is determined by radio ground-tracking instruments (RAWIN observation). This same data is used in the construction of the Skew T, log p Diagram and winds aloft reports. Radiosonde observations are made twice a day at 0000Z and 1200Z at approximately 80 stations in the United States.

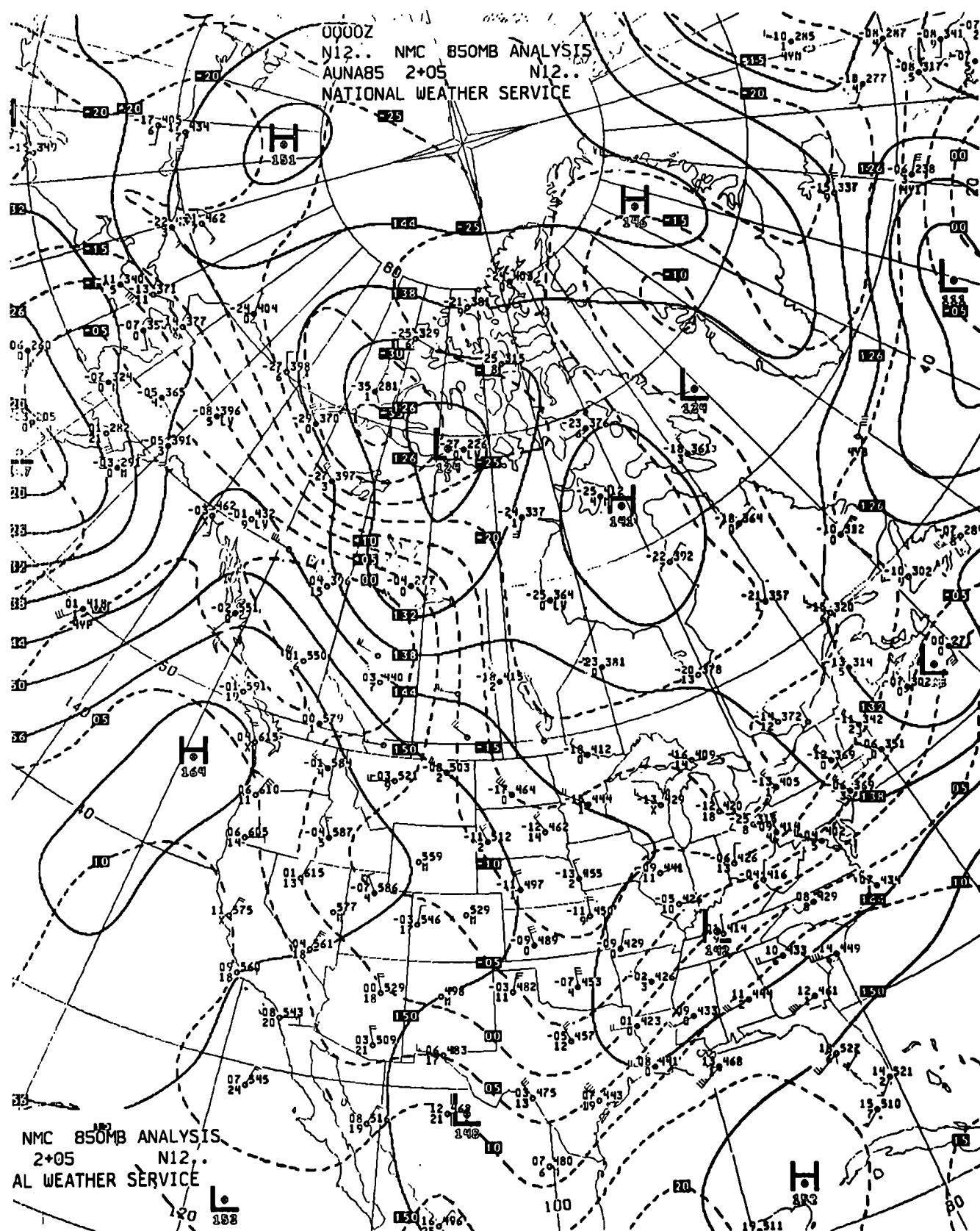


Figure 14-1. An 850-millibar constant pressure chart.

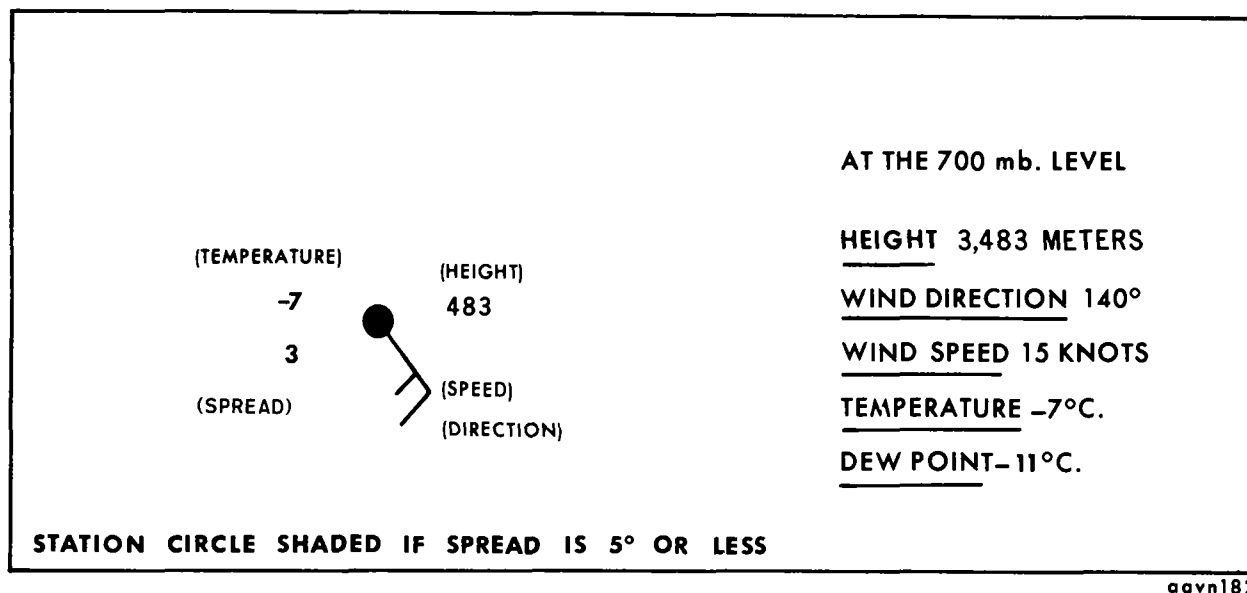


Figure 14-2. Station model on a constant pressure chart.

14-4. Methods of Plotting

The station model on the constant pressure chart (fig 14-2) includes the wind direction and speed, the altitude of the constant-pressure level, the temperature in degrees centigrade, and the temperature/dew point spread in degrees centigrade.

a. Wind. The wind arrow plotted from the data obtained by RAWIN observation shows the direction from which the wind is blowing (fig 14-2). The speed of the wind is shown by the barb and pennant system. A full barb represents 10 knots wind speed, a half barb 5 knots, and a pennant (flag) 50 knots. When used, the half barb is placed midway on the shaft to prevent confusion with a whole barb.

b. Altitude. At stations where the observation has been made with radiosonde equipment, the altitude of the pressure level above MSL is shown (fig 14-2). On the 850- and 700-millibar charts this altitude is plotted in whole meters with the first digit missing; e.g., 483 represents 1,483 meters on the 850-millibar chart and 3,483 meters on the 700-millibar chart. On the 500- and 300-millibar charts the altitude of the pressure level is indicated in tens of meters; e.g., 534 represents 5,340 meters and 948 represents 9,480 meters. When working with the 850- and 700-millibar charts, the aviator must check the chart pressure level in the lower left-hand corner of the chart to read the altitude properly. A plotted value of 380 would logically be 1,380 meters at the 850-millibar level and 3,380 meters at the 700-millibar level.

c. Temperature and temperature/dew point spread. The temperature and temperature/dew point spread are plotted to the left of the station model (fig 14-2). Upper air temperatures are always in degrees Celsius. When the temperature/dew point spread is 2° C. or less, clouds often exist at that level. Solid shad-

ing of the station circle indicates spread is 5° or less. An "M" indicates missing data.

14-5. Isoline Analysis

a. Contour Lines (Isohypses). Contour lines are solid black lines joining points of equal elevation (fig 14-1). The contour lines are labeled in tens of meters; i.e., 138 means 1,380 meters, 294 means 2,940 meters, 546 means 5,460 meters, and 936 means 9,360 meters. An interval of 60 meters between contour lines is used on the 850-, 700-, and 500-millibar charts. A 120-millibar interval is used on charts at and above the 300-millibar level.

(1) Wind speed and direction can be interpreted from the contour lines in the same manner as from isobars on the surface weather map, even though the principle of their construction is reversed. The wind-flow in the Northern Hemisphere is parallel to the contour lines clockwise around areas of high elevation and counterclockwise around areas of low elevation. The closer the isohypse spacing, the faster the speed of the wind.

(2) Closed areas labeled with an H or L are not interpreted as regions of high or low pressure, but are areas of high or low elevation, respectively. A region of high elevation on a constant-pressure chart may be directly over a region of low pressure at the surface.

(3) Steering levels for the surface pressure systems may be obtained from these charts. *For example*, if closed contour lines are present up to the 500-millibar level, but open contour lines appear on the 300-millibar chart over the same area, the surface pressure system will tend to move in the direction of windflow on the 300-millibar chart. Shallow surface pressure systems usually move at the greatest speed. Most of the winds on the charts at 10,000 feet and

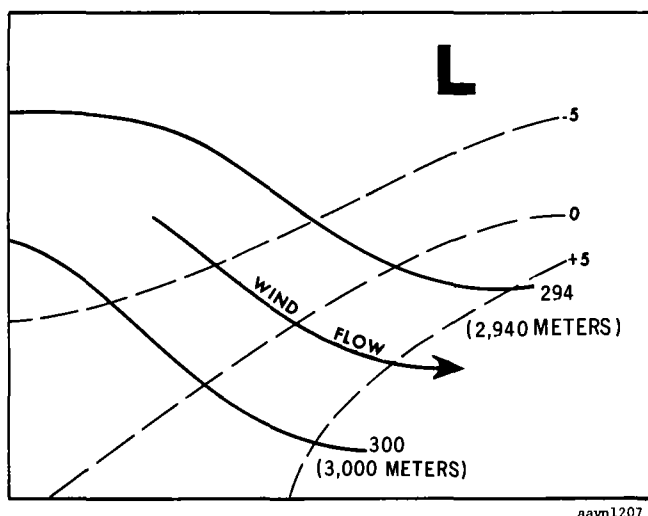


Figure 14-3. Cold air advection.

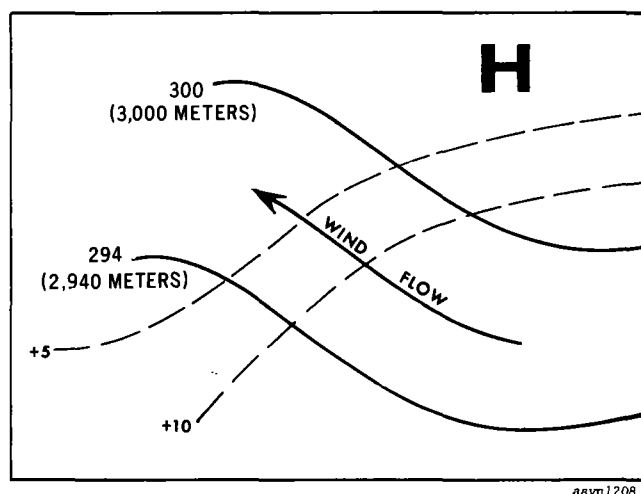


Figure 14-4. Warm air advection.

higher over the United States have a west-to-east component typical of the primary circulation.

b. Isotherms. Isotherms are dashed lines joining points of equal temperature at 5° C. intervals (fig 14-1). Weather station personnel may color these lines red when time permits. When the temperatures across a front on the constant-pressure charts change as much as 5° C. in a distance of 200 miles or less, the front is usually active. Where isotherms cross the contour lines at a sharp angle, warm or cold air advection is occurring at that altitude. Cold air advection aloft (fig 14-3) tends to fill a Low or intensify a High at the surface. Warm-air advection aloft tends to deepen a Low or weaken a High at the surface (fig 14-4).

c. Isotachs. Isotachs are dotted lines joining points of equal wind speed and are drawn on the 300- and 700-millibar level constant-pressure chart where strong wind speeds generally exist. Isotachs indicate

wind speed but not the direction of windflow. Areas of strongest wind with close isotach spacing indicate that the wind speed is changing rapidly in a short distance. The abrupt change in wind speed causes a shear action which may cause clear air turbulence. The greatest wind shear is associated with maximum isotach centers. The isotachs are drawn for intervals of 20 knots and the values are shown with a "K" for ease of identification (fig 14-5). Shading is used to portray the jet stream and show areas of highest winds (normally winds above 80 knots in summer and 100 knots in winter).

14-6. Jet Stream

a. Definition. The jet stream is a strong meandering current of air near the tropopause over the Temperate Zone that changes altitude and latitude with the seasons. The windflow has a west-to-east component with speeds in excess of 50 knots. At times the jet stream takes the form of a continuous river of air encircling the Northern Hemisphere. More frequently it is found in segments from 1,000 to 3,000 miles in length, 100 to 400 miles in width, and 3,000 to 7,000 feet in thickness (fig 14-6). There are normally two jet stream axes in the Northern Hemisphere—one between the arctic and polar air masses, and one between the polar and tropical air masses. The location of a jet stream is generally drawn locally on pressure charts as solid black arrows.

b. Altitude. Jet stream winds are found where breaks appear in the tropopause. The average height of the tropopause (*d* below) over the United States is 35,000 feet. This is the ideal altitude for maximum winds of the jet stream core, although jet streams have been recorded as low as 15,000 feet and as high as 50,000 feet. The altitude of the jet stream varies along its course, and the height of the complete segment may change slightly from day to day.

c. Latitude. Jet streams are found between 20° and 60° north latitude with equal frequency in summer and winter. The polar jet migrates with the outbreaks of cold polar air from the north. During the winter season, the cold air may push as far south as Cuba, with the jet stream axis as far south as Florida. During the summer season, the cold-air outbreaks are weakened and the jet stream is typically located near the Canadian border. Daily variation in latitude of the jet stream is slight.

d. Tropopause. The tropopause is the boundary between the troposphere and the stratosphere. It is not a layer but a plane of transition marking the upper limit of the temperature decrease with height, vertical air currents, and moisture content. The tropopause is not a continuous boundary. It has large distinct breaks above air masses of different density (fig. 14-7). There is a significant temperature change with

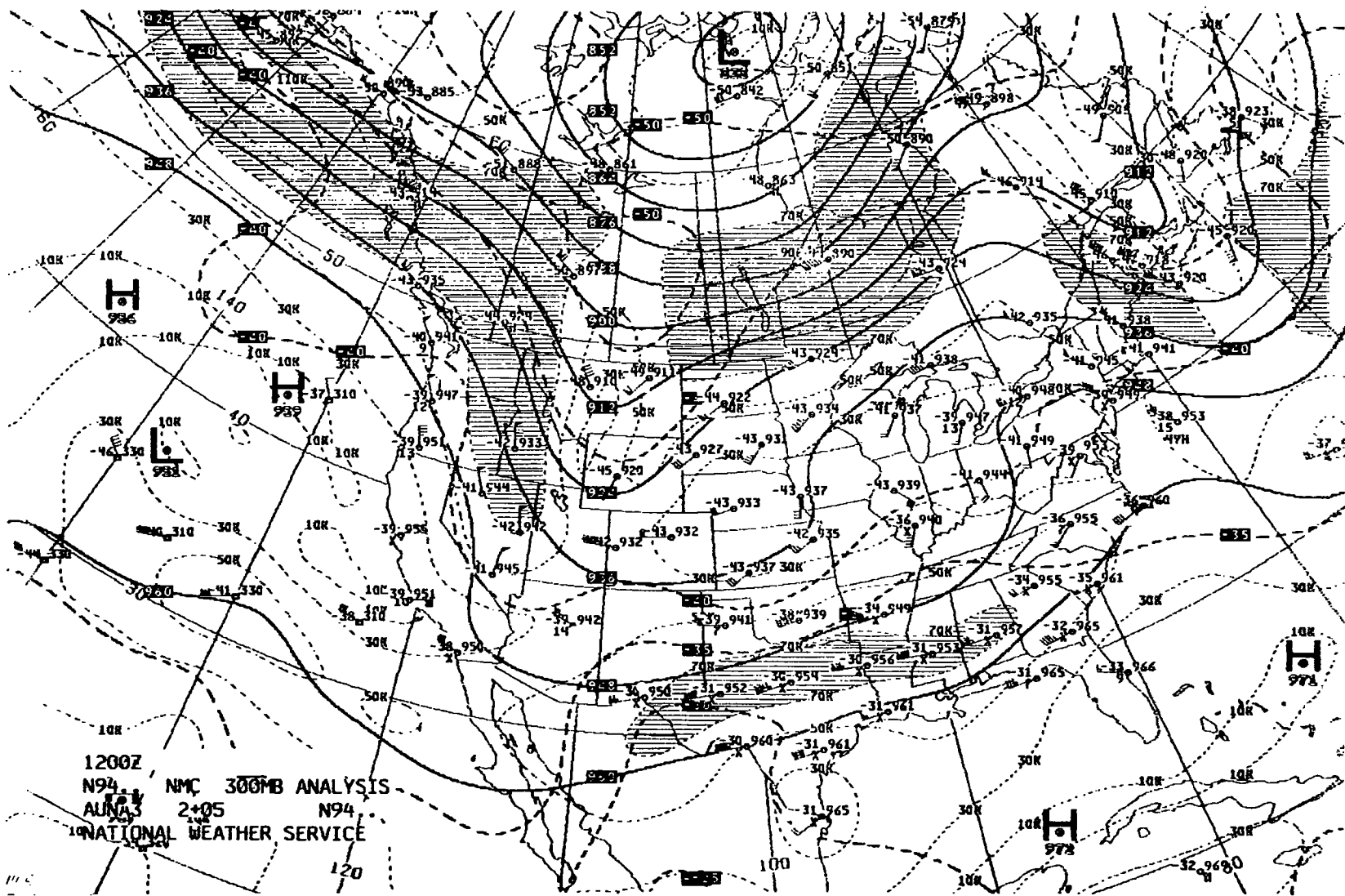


Figure 14-5. Isotachs, contour lines, and jet stream as depicted on a 300-millibar constant pressure chart.

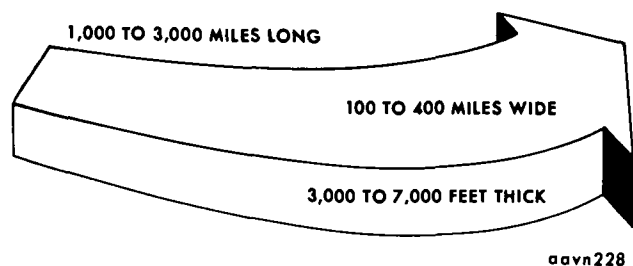


Figure 14-6. Size of a jet stream segment.

latitude across these breaks at high altitudes. The air south of the break in the tropopause is colder than the air north of the break because the temperature lapse rate extends through a deeper layer of the atmosphere to the south. *At the base of the stratosphere, temperatures are colder over the Equator than they are over the poles.* This thermal gradient sets the air into horizontal motion at great speeds, and Coriolis force deflects it sharply to the east. Thus, a strong flow of westerly winds forms at the break in the tropopause; this flow is the *jet stream* (fig 14-8). The jet stream can frequently be located by following a cold frontal surface from the ground to the point where the frontal boundary intersects the 500-millibar level. The jet stream is usually above this point at an average altitude of 30,000 feet (fig 14-8).

e. Wind Speed. When jet streams move southward, the wind speed tends to increase—if two jet streams exist over the United States, the more southerly one usually contains the stronger wind velocities. Wind speeds up to 291 knots have been observed in the jet core, but the average speed is approximately 150 knots. The high-velocity winds of the jet stream extend for a great distance along the length of the stream, but decrease rather rapidly above, below, and on either side of the central core of maximum winds (maximum isotach centers) (fig 14-9).

f. Wind Shear. The wind speed of a jet stream decreases rapidly to the north (polar air mass side) and more slowly to the south (tropical air mass side). The horizontal wind shear (change in wind speed in the horizontal plane) outward from the jet stream core may be as much as 100 knots in 100 miles north of the stream and as little as 25 knots in 100 miles south of the stream. The vertical shear (change in wind speed with height) may be 3 to 4 knots per thousand feet above and below the maximum wind core. If the aviator encounters an adverse jet stream, a descent or climb toward the polar side of the stream will effect the most abrupt decrease in headwind velocity.

g. Clear Air Turbulence. Extreme windshear areas (8 knots per 1,000 feet) may cause *clear air turbulence*, which denotes the bumpiness sometimes experienced while flying in cloudless skies at high altitudes. This bumpiness may be of sufficient intensity

to cause serious stresses on the aircraft and physical discomfort to the aviator. Clear air turbulence is generally associated with changing wind velocities with height (vertical-wind shear) in and near the maximum wind speed centers of the jet stream. The length of the turbulent area varies from 50 to 100 miles, the width from 5 to 20 miles; the thickness averages 2,000 feet. If the aviator encounters significant clear air turbulence, he should change altitude to avoid the strong wind shear and follow procedures established in the specific operator's manual for flight in turbulent air.

14-7. Contrails

a. General. The formation of condensation trails, commonly called *contrails*, presents serious problems to aircraft operating against an enemy. Contrails hamper operations by revealing the location, number, course, and type of aircraft. Even if enemy radar units are jammed, the aircraft can be visually spotted. The cirrus clouds formed by the contrails may interfere with formation flights in rendezvous areas for several hours. The two types of contrails are *aerodynamic* and *engine exhaust*.

(1) *Aerodynamic contrails.* Aerodynamic contrails are caused by the reduction of pressure when air flows at high speed past an airfoil. They form at the tips of wings and propellers during performance of extreme flight maneuvers, such as sharp pullouts and high-speed diving turns. They occur at altitudes where the atmosphere is near saturation. These trails are of short duration; a small change in altitude or reduction in speed may stop their formation.

(2) *Engine exhaust contrails.* Exhaust contrails from aircraft engines form when the water vapor in the exhaust gas mixes with and saturates the air through which the aircraft is flying. Aircraft fuel is a hydrocarbon which, upon combustion, results in the addition of water vapor and sublimation nuclei to the wake of the aircraft. The amount of exhaust contrail formation is a function of relative humidity, pressure, and temperature. The maximum period of exhaust contrail formation is in the winter season. In very cold arctic air, these contrails may even form at the surface. A change in altitude or power setting may eliminate exhaust contrails.

b. Relation of Contrails to Cirrus Clouds. A band of cirrus clouds approximately 100 miles wide extends from horizon to horizon below and to the south of a typical jet stream. Contrails forming near this cirrus band are difficult to distinguish from the original cloud layer.

14-8. Haze Layers

Haze layers invisible to ground observers are frequently encountered in the upper troposphere. The

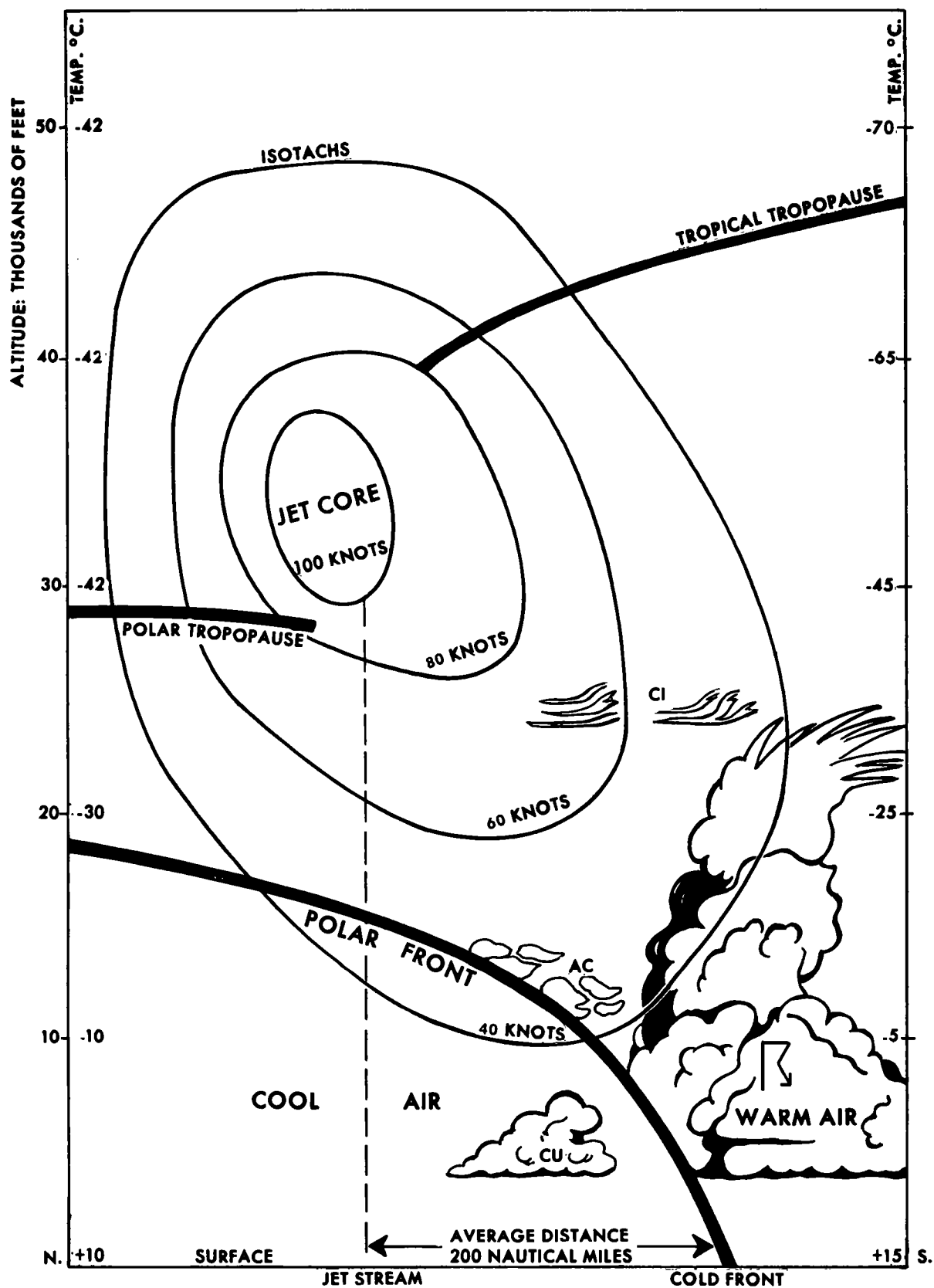


Figure 14-7. Jet stream (vertical cross section).

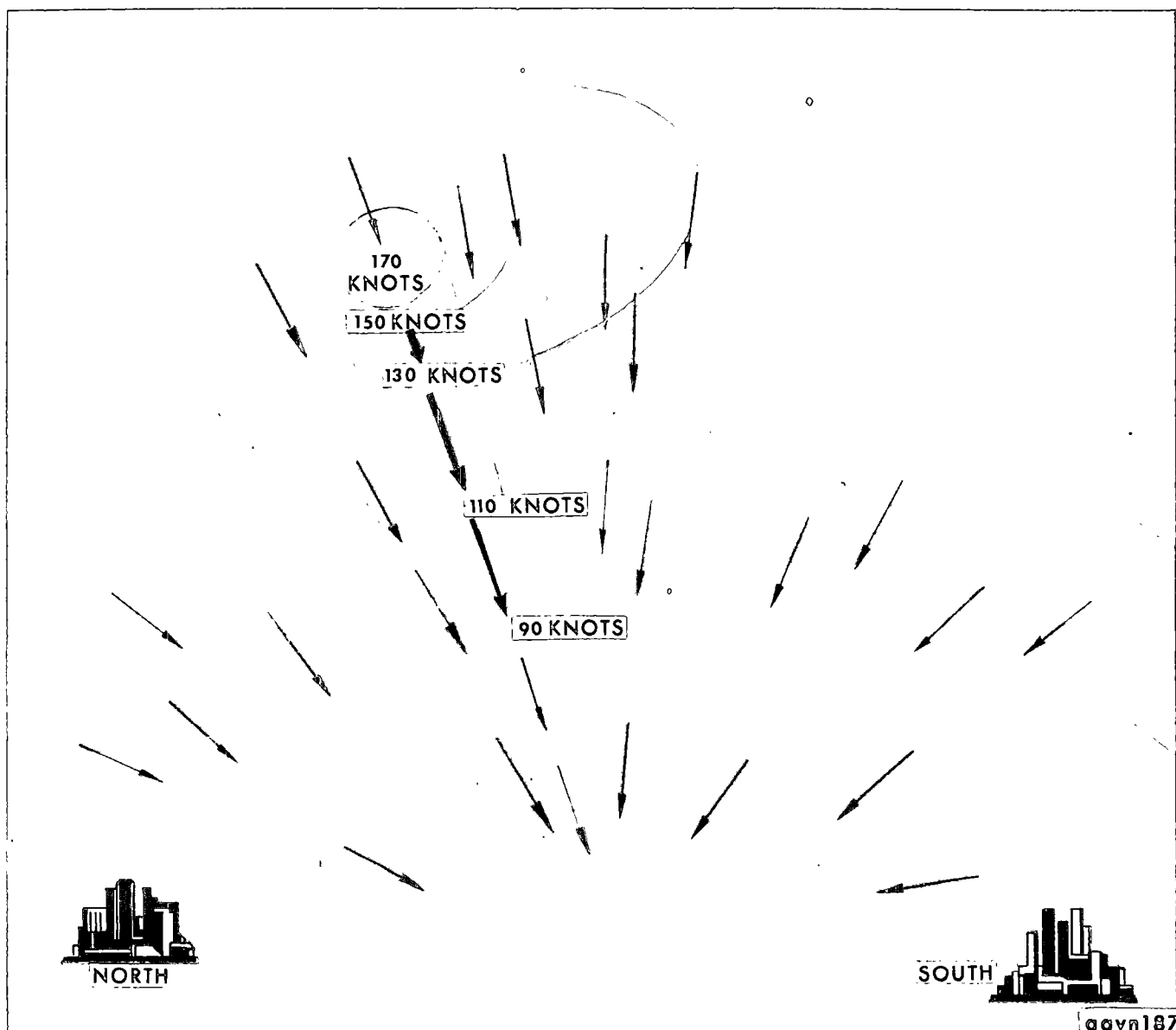


Figure 4-8. Windflow in a jet stream.

base of the haze layers is a gradual transition from clear sky to thick haze, but the tops have a more definite boundary. Although the horizontal visibility above the haze is excellent, air-to-ground visibility is sometimes reduced to zero, especially when the rays of the sun intersect the layer at an angle. Generally, high-altitude haze layers form in stagnant air masses.

14-9. Canopy Static

Canopy static is similar to precipitation static encountered at lower levels. When solid particles of ice crystals in cirrus clouds, dust, or of dry haze layers brush against the aircraft canopy and structural surface, they build up a static electric charge on the surface. The discharge of this electricity into the air or within the aircraft produces static in the radio equipment and is disconcerting to the aviator. The discharges can occur in rapid succession and can be

observed within the aircraft as a continuous electrical disturbance. A change of altitude to remove the aircraft from the frictional contacts and/or a reduction in airspeed to reduce the skin friction should eliminate the canopy static.

14-10. Altimeter Error

Under certain conditions of temperature and pressure, the combined error in the altimeter reading at flights near 18,000 feet may be as much as 2,000 feet. Figure 14-10 illustrates a flight from an area of standard atmospheric pressure and temperature (Station G) to an area of surface high pressure with cold air (Station D). Although altimeter settings are received at regular intervals along the route and inflight corrections are made accordingly, a disastrous loss of altitude occurs along the route.

a. The 700-millibar constant-pressure chart indi-

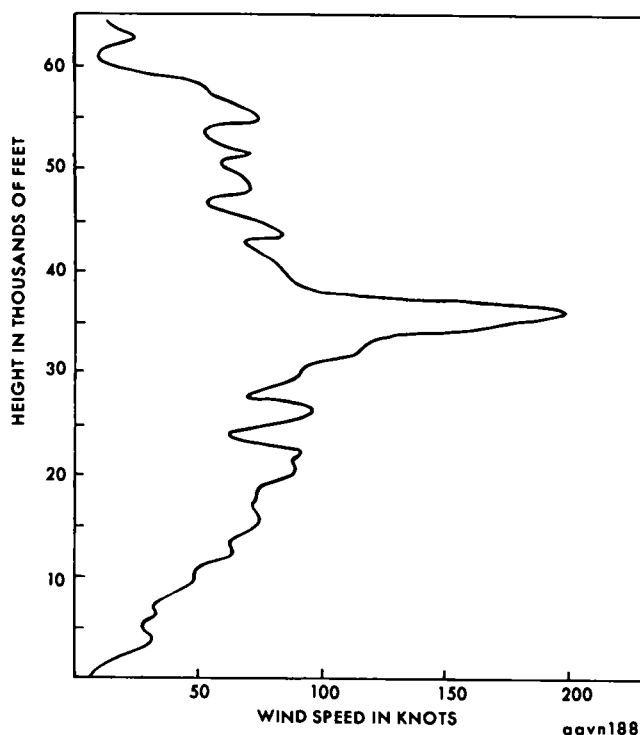


Figure 14-9. Vertical wind speed variation in a jet stream.

cates that the pressure level is at 10,000 feet over the point of departure (G) and decreases in altitude to 9,400 feet over the mountains (D). At flight level the aircraft is flying into a region of low pressure-elevation aloft. Following the 700-millibar pressure level without changing the altimeter setting will

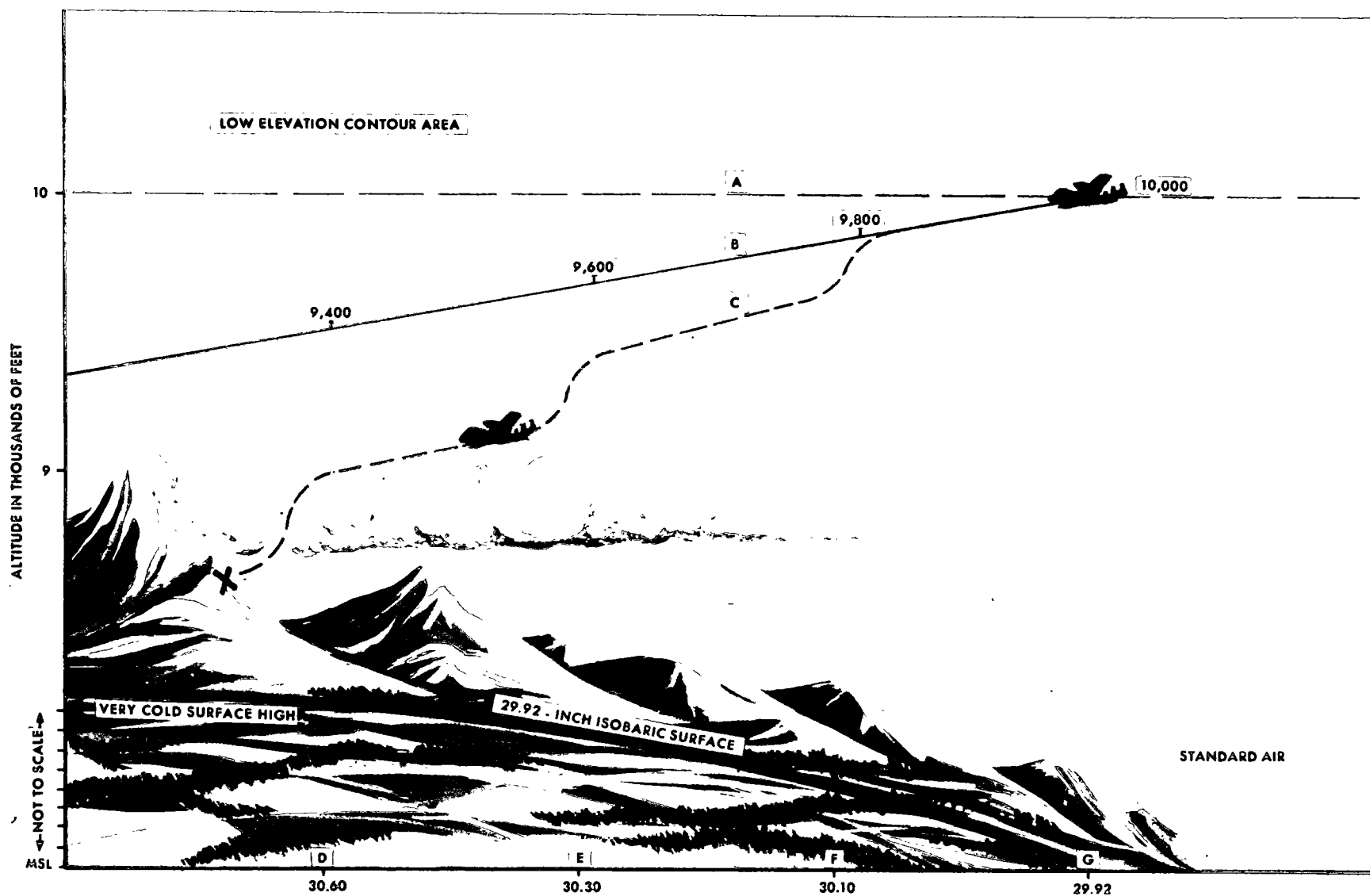
result in an indicated altitude of 10,000 feet while the aircraft is actually descending to 9,400 feet. The altimeter would read 600 feet higher than the true altitude of the aircraft.

b. Resetting the altimeter over Station F will add 180 feet to the indicated altitude; i.e., the difference between 30.10 and 29.92 is eighteen-hundredths of an inch—the equivalent of 180 feet of altitude where 1 inch is equal to 1,000 feet of altitude. The aviator will *descend* 180 feet to remain at the indicated 10,000-foot altitude.

c. Over Station E the aviator will descend another 200 feet after resetting his altimeter for the surface pressure.

d. Over Station D, resetting the altimeter will cause him to descend another 300 feet to remain at an indicated 10,000 feet.

e. The total error in the indicated altitude due to surface altimeter settings is 680 feet; i.e., the altimeter would read 680 feet higher than the true altitude of the aircraft. When this error is added to the 600-foot error caused by the lowering of the 700-millibar pressure level aloft, as determined from the constant-pressure chart, the total combined error is 1,280 feet. The aircraft is actually 8,720 feet MSL while indicating 10,000 feet MSL. By realizing this before takeoff, the aviator will recognize that the minimum acceptable flight altitude for traversing the 9,000-foot mountain ranges around Station D will be 11,000 feet. With proper flight planning and use of weather station facilities, this type of error can be avoided.



- A PROPOSED FLIGHT PATH OF 10,000 FEET MSL.
- B ACTUAL HEIGHT OF 700-mb PRESSURE LEVEL ON CONSTANT PRESSURE CHART.
- C FLIGHT PATH USING CONSTANT ALTIMETER SETTING FROM INITIAL SURFACE STATION (G)
- D ENROUTE REPORTED ALTIMETER SETTINGS (D, E, F)

dav189

Figure 14-10. Combined altimeter error aloft.

CHAPTER 15

RADAR AND WEATHER

15-1. General

Radar engineering developments in the past few years have produced weather observing capabilities that offer a unique service for the meteorologist and the aviator. Radar is now an integral part of the science of meteorology and an effective aid in adverse weather flying. Airborne weather radar is now standard equipment on most air carrier and large military aircraft with an ever increasing usage by the medium twin-engine and lighter type aircraft.

15-2. Basic Principles of Radar Set Operation

Radar equipment consists essentially of a very short-wave directional radio transmitter and receiver. The transmitter emits brief pulses of energy which are radiated from the radar tower (fig 15-1) in a directed beam. By electronic timing of the interval (microseconds) between the emission of the transmitted signal and the reception of the reflected signal (echo), it is possible to determine the distance to a reflecting object. A good weather radar set at weather stations has an average range of 150 to 200 miles, although under some atmospheric conditions the range is much greater. The distances and bearings of detected objects are electronically computed and automatically depicted on the radar scope. By continuous scanning, the operator maintains a representation of the reflecting objects on the radar scope (fig 15-2).

15-3. Echoes

For all practical purposes, the only atmospheric condition that will reflect an echo is water droplets or ice particles. The intensity (brightness) of the reflection on the scope is a direct indication of the size and number of water droplets, ice particles, and/or precipitation in the atmosphere.

a. On a standard weather-detection radar scope, many or large raindrops or hail produce strong echoes; fewer or smaller liquid drops and snowflakes produce weaker echoes; and cloud particles are so small that they produce very weak echoes or none at all.

b. Radar shows only that portion of a storm which contains water droplets or ice crystals of sufficient size and number to produce the echoes on the scope.

This in itself helps to detect storm areas, and the movement and changes in size can be monitored in successive observations. A more important aspect of the use of radar equipment is that a direct relationship exists between the amount of turbulence in a storm and the rainfall (precipitation) gradient. (Gradient refers to how rapidly the rate of rainfall changes with respect to distance.) A change from no rainfall to heavy rainfall in a short distance would be called a steep gradient. Steep gradients produce sharp shear and turbulence. Conversely, a shallow rainfall gradient, even though the precipitation may be very heavy, would not have much associated turbulence. In addition, certain unique scope patterns of precipitation have been correlated to hail shafts and tornado occurrences. Hooks, fingers, and particularly rapidly forming protrusions from crescent indentations have been observed with tornadoes (fig 15-3). When the tornado itself appears, it usually takes the shape of a figure "6" on the scope (fig 15-4).

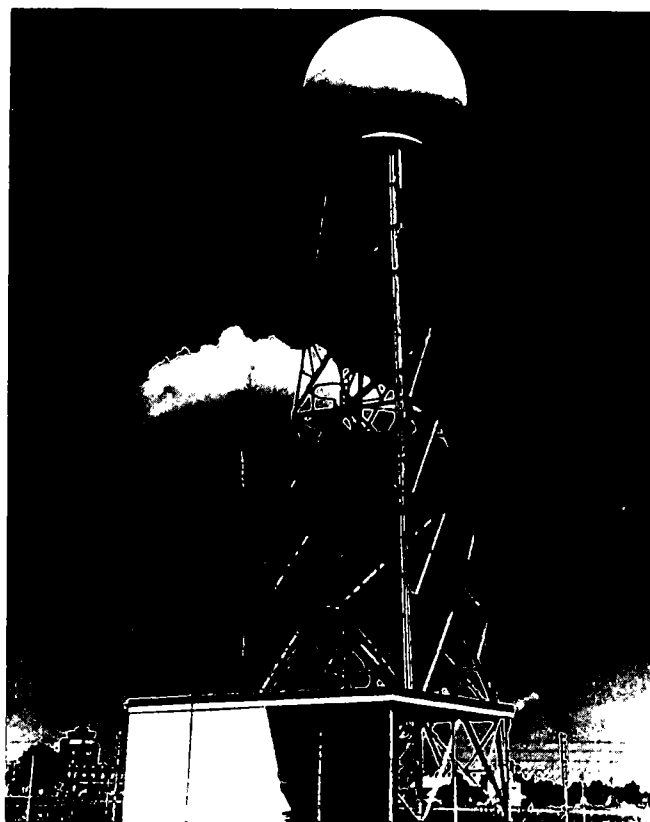


Figure 15-1. Radar tower.

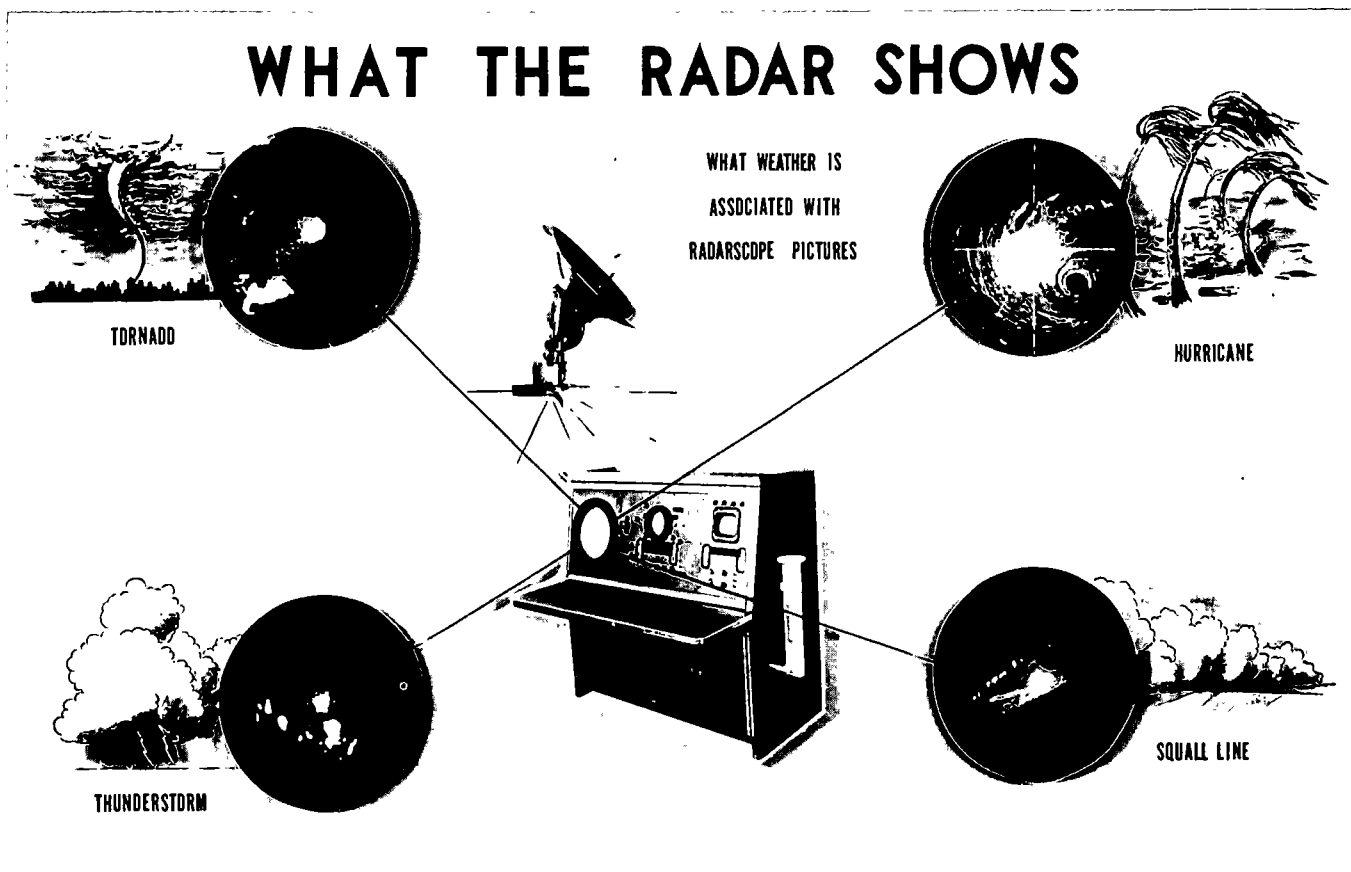


Figure 15-2. Radar scope.

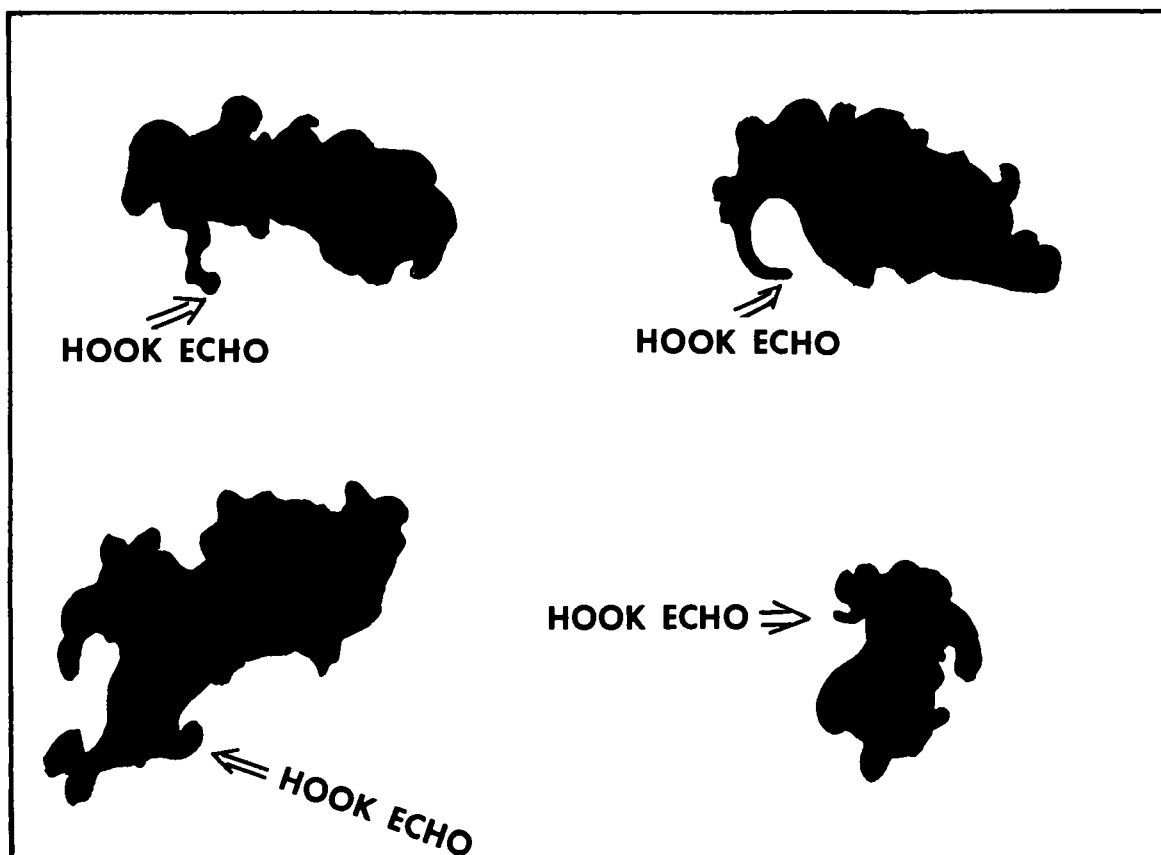


Figure 15-3. Hook echoes associated with severe thunderstorms may indicate tornado occurrence.



Figure 15-4. Hook echo associated with Meriden Tornado May 19, 1960 (radarscope of Topeka, Kansas, at 1831 CST). Distance between concentric range markers 5 nautical miles.

Note. With all the significant breakthroughs in the use of radar for weather analysis, it is still not possible to predict the exact time or place of occurrence of severe thunderstorms or tornadoes. However, it is possible to identify areas in which there is a high probability of severe thunderstorm and tornado generation.

15-4. Weather Radar Network

The National Weather Service operates a network of approximately 90 stations which is augmented by several Department of Defense (DOD) and Federal Aviation Administration (FAA) radar sets to provide radar weather coverage of the conterminous United States. Approximately 15 DOD radars provide coverage to Alaska with data input to the Anchorage Forecast Center. Some FAA flight service stations located near radar equipped weather service locations have repeaterscopes. This allows them to use the radar display of significant weather for local weather analysis and as an effective tool for briefing purposes. The National Severe Storms Forecast Center (NSSFC) at Kansas City, Mis-

souri, makes use of this radar network in conjunction with their continuous monitoring of atmospheric conditions to provide the country as much advance warning of severe weather as possible. Their weather warnings are issued by use of National Teletype circuits, VHF—FM radio weather transmissions, recorded telephone announcement systems, local radio and television newscasts, and local alarm systems such as sirens. For the aviator, radar reports, severe weather forecast bulletins, and radar summary charts offer help in the planning stages of flight. Radar advisories from air traffic control and pilot to metro/en route flight watch service facilities support him en route (chap 17).

15-5. Radar Reports (RAREP) (SD's)

The surface weather radar sets now in operation are used to identify and track storms over most of the United States. The stations which observe significant radar echoes transmit the information on the weather teletypewriter circuits every hour. These transmissions (SD's) are known as RAREP. All stations, and especially those which are not equipped with radar sets, receive much valuable information from RAREP. An example of a RAREP is shown in figure 15-5. These reports can be decoded using the legend shown in figure 15-6. The reports give the location identifier; time of report; and character of echoes (e.g., isolated, area, or line) to include coverage in tenths, intensity, location and dimensions, movement and maximum top of detectable moisture, plus a remarks section.

15-6. Severe Weather Forecasts and Bulletins

Severe weather forecasts and bulletins (WW) are transmitted over teletype circuits at irregular intervals by the National Severe Storms Forecast Center (NSSFC), Kansas City, Missouri. Additionally, they will appear on radar summary charts (para 15-7) with their assigned number and valid time period. A sample severe weather forecast is shown in figure 15-7 and is explained as the 423d weather warning of the year. The forecast was issued at 0140Z on the 5th

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SDUS KNKA 170057
AQQ 0034 AREA 1 TRW+5R-/NC 60/165 100/145 154/175 184/150
245/165 203/20 CELLS 2635 MT 290 AT 90/107 MOST TOPS BLO 230
INCLS 1R

AYS 0035 AREA 4RW/NC 85/115 196/110 40W CELLS 2610 MT 230
AT 116/70 PRTLY ALF BASES 110

BNA 0032 AREA 3TRW/NC 10/80 135/95 100W CELLS 2820 MT 210
AT 15/25
```

Figure 15-5. Sample radar report—RAREP.

TA B-0-12
(Rev. 6-73)**CONDENSED EXPLANATION OF RAREP (SD) CODE**

EFFECTIVE JUNE 1, 1973

28 November 1973

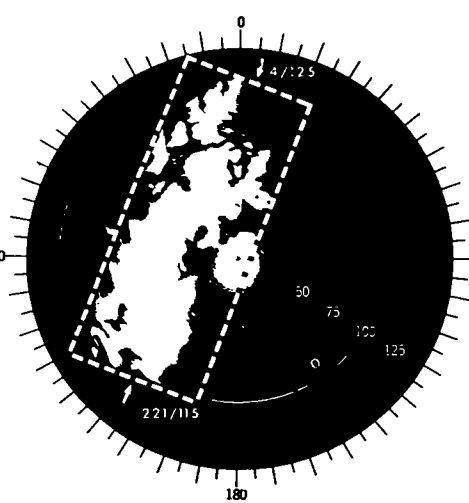
LOCATION IDENTIFIER	TIME OF REPORT	CHARACTER OF ECHOES	WEATHER AND INTENSITY	INTENSITY TENDENCY	LOCATION AND DIMENSIONS OF ECHOES	MOVEMENT	ECHO TOPS	REMARKS																					
EVV	1640Z	AREA 6	TRW +A	/+	4/125 221/115 100W	2715 CELLS 2325	MT 550 at 310/45	3/4 INCH HAIL 310/45																					
DECODED REPORT Evansville Indiana hourly Radar Report (RAREP) taken at 1640Z. An area 6 tenths covered with echoes, containing thunderstorms producing heavy rainshowers and occasional hail at the surface. These echoes are increasing in intensity. Area extends from 4° 125 nautical miles to 221° 115 nautical miles, is 100 nautical miles wide. The area is moving from 270° at 15 knots, the cells within the area from 230° at 25 knots. Maximum top of the detectable moisture is 55,000 feet MSL at 310° 45 nautical miles. Hail 3/4 inch in diameter was reported with this echo. The above report is for the echo area in the radarscope picture. The slash mark (/) is used to separate the intensity of the echo from the intensity tendency.					INTENSITY TREND TREND Increasing + Unchanging NC Decreasing - New NEW The intensity trend is evaluated in terms of a net change in the characteristic intensity equal to approximately one intensity category (light to moderate) during a specified time period, which is one hour for lines and areas and fifteen minutes for cells.		DIMENSIONS OF ECHOES Width (W) or diameter (D) are reported in nautical miles. The average width of lines and rectangular areas, and the average diameter of cells and roughly circular areas, are reported. MOVEMENT Direction, to nearest ten degrees from which, and speed in knots with which, the echo is moving. Both cell and system movement are reported when available. Line movement is reported in terms of the component perpendicular to the axis.																						
TIME OF REPORT Time of observation (24-hour clock) in Greenwich Mean Time. Observations are normally taken at 40 minutes past each hour. When a special observation is taken, the contraction SPL is placed between the Time of Report and Character of Echoes.					RADAR SCOPE  ECHO PATTERN																								
CHARACTER OF ECHOES <table border="0"> <thead> <tr> <th>CHARACTER</th> <th>DEFINITION</th> <th>CONTRACTION</th> </tr> </thead> <tbody> <tr> <td>Isolated echo</td> <td>Independent convective echo</td> <td>CELL</td> </tr> <tr> <td>Area</td> <td>A grouping of related or similar echoes</td> <td>AREA</td> </tr> <tr> <td>Line</td> <td>Related or similar echoes forming a line at least 30 miles long with a length-to-width ratio of at least 5 to 1</td> <td>LN</td> </tr> <tr> <td>Stratified elevated echo</td> <td>Precipitation aloft</td> <td>LYR</td> </tr> <tr> <td>Spiral band area</td> <td>Curved lines of echoes, including wall cloud, which occur in connection with hurricanes, tropical storms, and typhoons</td> <td>SPRL BAND AREA</td> </tr> <tr> <td>Fine line</td> <td>Narrow, nonprecipitation echo associated with a meteorological discontinuity</td> <td>FINE LN</td> </tr> </tbody> </table> NOTE: Echo coverage in tenths within an area, line or elevated echo is given by the number which immediately follows the word or contraction describing the character of the echoes. For example, AREA6 means that echoes cover 6 tenths of the outlined area.									CHARACTER	DEFINITION	CONTRACTION	Isolated echo	Independent convective echo	CELL	Area	A grouping of related or similar echoes	AREA	Line	Related or similar echoes forming a line at least 30 miles long with a length-to-width ratio of at least 5 to 1	LN	Stratified elevated echo	Precipitation aloft	LYR	Spiral band area	Curved lines of echoes, including wall cloud, which occur in connection with hurricanes, tropical storms, and typhoons	SPRL BAND AREA	Fine line	Narrow, nonprecipitation echo associated with a meteorological discontinuity	FINE LN
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PRECIPITATION SYMBOLS <table border="0"> <tbody> <tr> <td>IP ICE PELLETS</td> <td>SW SNOW SHOWERS</td> <td>ZR FREEZING RAIN</td> </tr> <tr> <td>L DRIZZLE</td> <td>T THUNDERSTORMS</td> <td>ZL FREEZING DRIZZLE</td> </tr> <tr> <td>RW RAIN SHOWERS</td> <td>S SNOW</td> <td></td> </tr> <tr> <td>R RAIN</td> <td>A HAIL</td> <td></td> </tr> </tbody> </table> INTENSITY <table border="0"> <tbody> <tr> <td>LIGHT -</td> <td>VERY HEAVY ++</td> <td>UNKNOWN U</td> </tr> <tr> <td>MODERATE NO SIGN</td> <td>INTENSE X</td> <td></td> </tr> <tr> <td>HEAVY +</td> <td>EXTREME XX</td> <td></td> </tr> </tbody> </table>					IP ICE PELLETS	SW SNOW SHOWERS	ZR FREEZING RAIN	L DRIZZLE	T THUNDERSTORMS	ZL FREEZING DRIZZLE	RW RAIN SHOWERS	S SNOW		R RAIN	A HAIL		LIGHT -	VERY HEAVY ++	UNKNOWN U	MODERATE NO SIGN	INTENSE X		HEAVY +	EXTREME XX		LOCATION OF ECHOES 1. Locations of echoes are relative to the radar position. The azimuth in degrees true, and the distance in nautical miles, to salient points of the echoes are given. 2. If the echoes are arranged in a line, the azimuth and distance will be given to as many points along the axis of the line as are necessary to establish its shape. 3. If an irregularly shaped area is covered by echoes, the azimuth and range to salient points on the perimeter of the area will be reported as necessary to reconstruct the shape and size of the echo area. 4. If an area of echoes of roughly circular shape is observed, or if a single echo such as a thunderstorm cell is observed, the azimuth and range to the center of the area or cell will be reported.			
IP ICE PELLETS	SW SNOW SHOWERS	ZR FREEZING RAIN																											
L DRIZZLE	T THUNDERSTORMS	ZL FREEZING DRIZZLE																											
RW RAIN SHOWERS	S SNOW																												
R RAIN	A HAIL																												
LIGHT -	VERY HEAVY ++	UNKNOWN U																											
MODERATE NO SIGN	INTENSE X																												
HEAVY +	EXTREME XX																												
GENERAL NOTES SD (Storm Detection)—Radar Report (RAREP) Identifier. Identifies the message as a RAREP. When the report contains an important change in echo patterns, or some other special criteria given in the Weather Radar Manual, Part A has been met, it is designated as a special (SPL). Intensity of precipitation at distances exceeding 125 nautical miles from a WSR-57 or other radar of similar sensitivity, or 75 miles from other radars, will be reported as unknown (U). Intensities of snow, hail, drizzle, and ice pellets are not reported. One rainfall intensity category is selected to characterize each reported echo system. For convective systems, it is the maximum intensity in the system. For other systems, it is the intensity predominant in horizontal extent. Persisting echoes are indicated in remarks.					 U. S. DEPARTMENT OF COMMERCE National Oceanic and Atmospheric Administration NATIONAL WEATHER SERVICE SILVER SPRING, MD. 20910																								

Figure 15-6. Condensed explanation of RAREP (SD) code.

WW MKC 050140

MKC FCST NR 423 050140

AREA ONE SVR TSTM FCST

A ALG AND 60 MI EITHER SIDE OF
A LINE FM 30 MI SW OF MASON CITY IA
TO 20 MI S OF PEORIA ILL. VALID CUR-
RENT TIL 0600Z. PUB FCST ISSUED.

B SCTD SVR TSTMS WITH HAIL TO
3/4 INCH DIAM EXTRM TURBC AND MAX
SFC WND GSTS TO 60 KT. SCTD CBS
MAX TOPS TO 55 THSD FT.

C SQLN DVLPG IN NWRN IA EXPCD
TO MOV SE ABT 35 KT.

REMARKS. THIS FCST REVISED WW 421
AREA TWO.

Figure 15-7. Severe weather forecast (WW).

day of the current month. It is for Area One and is a severe thunderstorm forecast. "A" gives the detailed area of coverage as along and 60 miles either side of a line from 30 miles southwest of Mason City, Iowa, to 20 miles south of Peoria, Illinois. The valid time is shown as current to 0600Z. It also notes that a public forecast has been issued. Paragraph "B" gives the expected weather conditions as scattered severe thunderstorms with hail to 3/4-inch diameter with extreme turbulence and maximum surface wind gusts to 60 knots. Scattered cumulonimbus with maximum tops to 55,000 feet. Paragraph "C" gives the weather system expected to cause the severe conditions. In this example a squall line is developing in northwestern Iowa and is expected to move southeastward at about 35 knots. The final paragraph gives remarks

WW 421 covering Area Two. These reports are of particular value to air traffic control, weather personnel, and pilots. They will also be reflected in both terminal and area forecasts as well as in-flight weather advisories.

15-7. Radar Summary Charts

RAREP are plotted on charts (radar summary charts, fig 15-8) and transmitted over the facsimile circuits from 12 to 15 times a day (more often if weather conditions warrant it). These charts are prepared at the weather central in Kansas City, Missouri, by the Radar Analysis and Development Unit (ADUS). They provide a general overview of the locations where heavy precipitation appears as an echo on the ground-based weather radar equipment. Various symbols are used to further describe the conditions occurring and include scalloped lines inclosing areas and in this case points out that this warning revised of precipitation with the amount of echo coverage within the area as well as bases and tops of echoes, thunderstorms cells, and lines of thunderstorms with their associated direction and speed of movement. Additionally, notations such as NE (no echoes), NA (observation not available), and OM (equipment out for maintenance) are used to qualify to the user the reason for areas not showing echoes. When severe weather forecasts and bulletins (WW) are given, they will appear on the chart as a black dashed line with the identification number of the WW and its valid time shown in the lower left corner of the chart. A typical radar summary chart is illustrated by figure 15-8 and can be interpreted by using the legend shown in figure 15-9.

Note. Note that all references on these charts are to echo coverage, not cloud cover.

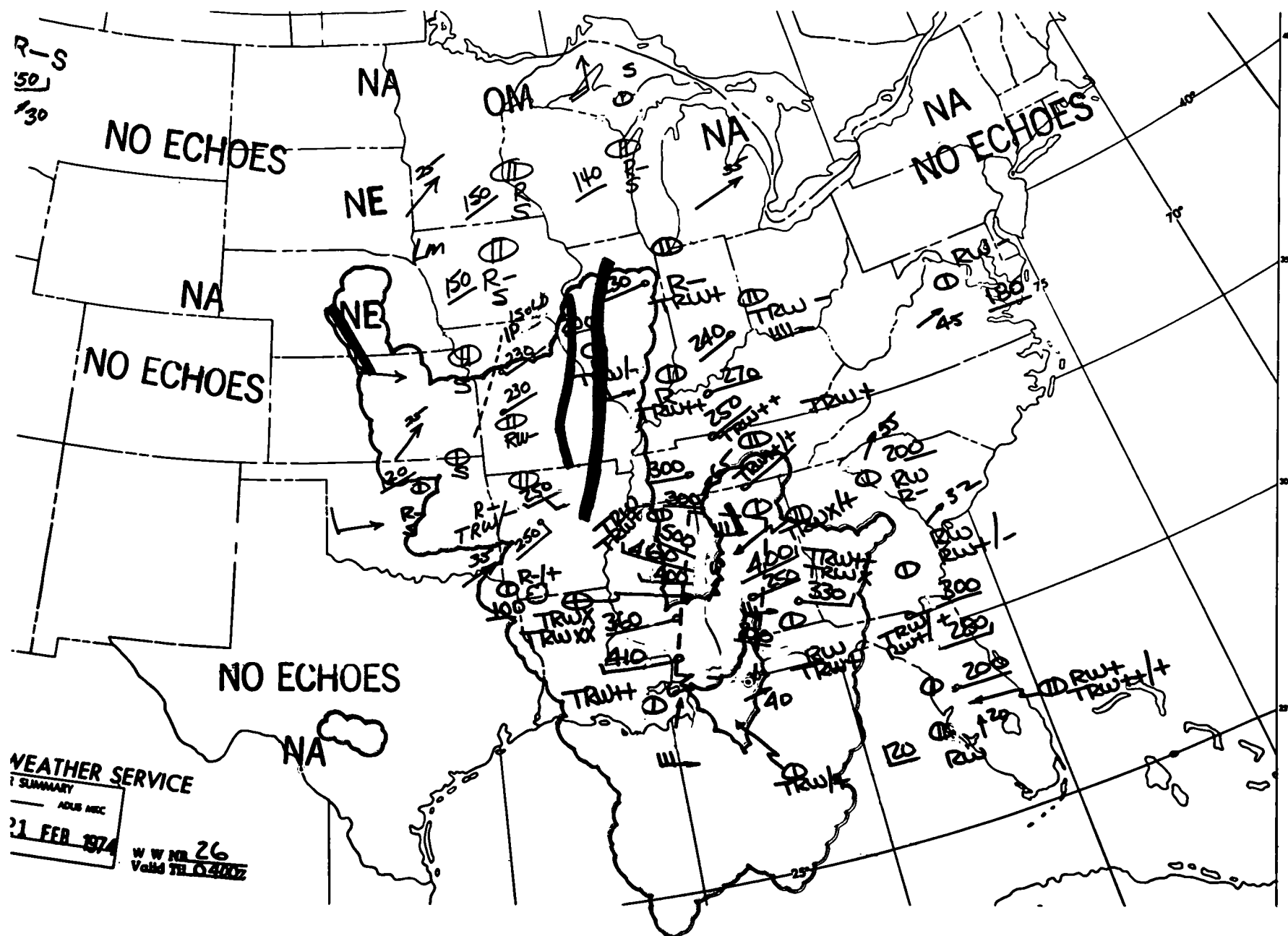


Figure 15-8. Radar summary chart.

RADAR SUMMARY CHART LEGEND

U.S. DEPARTMENT OF COMMERCE

Peter G. Peterson, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Robert M. White, Administrator

NATIONAL WEATHER SERVICE

George P. Cressman, Director

GENERAL

Two methods of data depiction appear on these charts. East of the Rockies radar reports are plotted and grouped in certain configurations. West of the Rockies, actual echo patterns from ARTC radar sites are shown. Most of the symbols used are common to both sections of the map.

SURFACE WEATHER ASSOCIATED WITH ECHOES

T Thunderstorm IP Ice Pellets
R Rain L Drizzle
RW Rain Showers ZR Freezing Rain
S Snow ZL Freezing Drizzle
SW Snow Showers A Hail

PRECIPITATION INTENSITY

— Very Light + Heavy.
— Light ++ Very Heavy
No Sign Moderate U Unknown

Intensity of echoes is given in terms of the estimated precipitation intensity. No intensity is ascribed to drizzle, hail, sleet or snow. Echoes located farther than a specified range, usually 125 nautical miles, are given an intensity of unknown or "U".

INTENSITY TREND

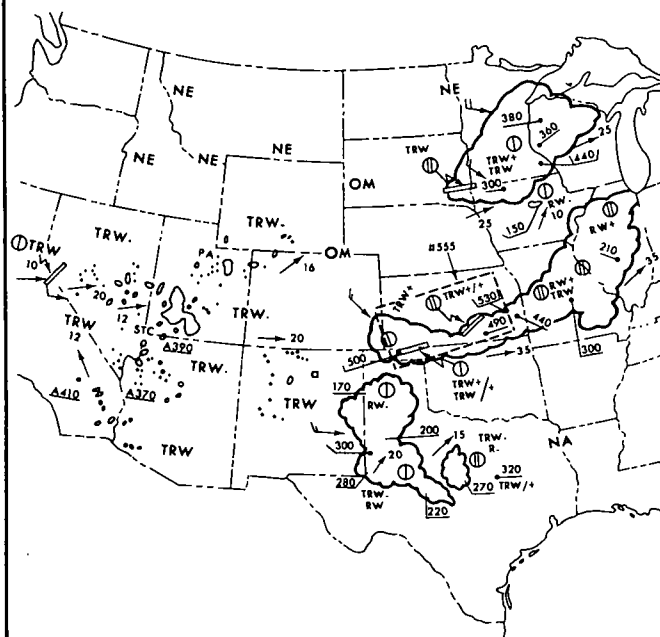
+ Increasing NEW New Development
— Decreasing

Intensity trend follows the precipitation intensity and is preceded by a slash mark. The absence of a symbol means that there has been no change in the intensity.

STATUS OF EQUIPMENT

NE No echoes
NA Observation not available
OM Equipment out for maintenance
CP Moderate to strong echoes reported only
STC Reduced detection capability within 30 miles of radar
MAG Radar on reduced power
Last three items from ARTC reports only

SAMPLE RADAR SUMMARY CHART WW NR 555 Valid Til 0200Z



MOTION OF ECHOES

→ V V Cell Movement - Speed in knots
→ Area or line movement--(10 kts/barb)
LM Little movement

ECHO HEIGHTS

hhh Height of echo tops
hhh Height of maximum reported echo top
hhh Height of echo bases
hhh Height of melting level
Ahhh Visual cloud top seen by aircraft
Heights are in hundreds of feet MSL.

CHARACTER OF ECHOES

☁ Area of echoes
/ Line of echoes
⊕ Solid Coverage within area or line is greater than 9 tenths
⊖ Broken Coverage within area or line is greater than 5 tenths but not greater than 9 tenths
⊙ Scattered Coverage within area or line is not greater than 5 tenths and not less than one tenth
⊗ Widely Scattered Coverage within area or line is less than one tenth
● Strong or very strong cell identified by one station
☀ Strong or very strong cell identified by two or more stations
○ Actual echo boundary copied from ARTC scopes
PA Partly Aloft
MA Mostly Aloft
Layers aloft associated with other echoes will be preceded by acronym for partly aloft or mostly aloft



Severe Weather Watch area with entry of number and valid time of watch.



CHAPTER 16 FORECASTS

Section I. INTRODUCTION

16-1. General

The aviator planning a flight is concerned with observed and forecast weather conditions along his route. Teletype sequence reports, surface weather maps, winds aloft reports, and atmospheric diagrams are consulted for past and present weather information. Weather forecasts for a proposed flight are available from several sources and in various formats.

16-2. Types of Forecasts

Forecasts are available at the weather station in the form of teletype transmissions, locally prepared forecasts, and facsimile prognostic charts. The aviator may also be advised of the development of potentially hazardous weather by radio transmission during flight. Each of the many types of forecasts is designed to serve a specific function so each varies to some extent in format and scope.

Section II. TELETYPE FORECASTS

16-3. Area Forecast

a. Aviation Area Forecasts (FA). Aviation area weather forecasts (FA) are prepared at Weather Service Forecast Offices (WSFO) listed in figure 16-1. These forecasts are made by each WSFO for a prescribed area of the country. They give a synopsis, describe significant clouds and weather, and show icing conditions expected in the area. The forecasts are made to both civil and military weather facilities through the teletype Weather Message Switching Center (WMSC), Kansas City, Missouri. Area forecasts are issued twice daily (fig 16-2) covering an 18-hour period with an additional 12-hour categorical (LIFR, IFR, MVFR, VFR) outlook (fig 16-3).

b. Interpretation of Area Forecast (fig 16-4). In the circuit heading, MSY is the station identifier of the forecast center (New Orleans, Louisiana); FA identifies the bulletin as an area forecast. This forecast was transmitted on the 30th day of the month at 1240 Zulu time. The forecast is valid from 1300Z Friday until 0700Z Saturday with an additional outlook from 0700Z to 1900Z Saturday. The area covered is Tennessee, Arkansas, Louisiana, Mississippi, Alabama, and Florida west of 85 degrees to include the coastal waters. All heights are above sea level unless noted.

(1) *Synopsis.* A strong high pressure ridge from Columbus, Georgia, southwestward to Lake Charles, Louisiana, will move slowly southward. A cold front with no associated significant clouds or weather across Michigan extending southwestward to Nebraska will move southeastward reaching a Dyersburg, Tennessee, to Chattanooga, Tennessee, line by

0700Z. This is a summary of the major features influencing the conditions in the forecast area.)

(2) *Significant clouds and weather.* Over the area, a few patches of visibility will be below 3 miles in ground fog, smoke, and haze until 1500Z. Otherwise, no significant clouds and weather. Outlook is VFR except marginal VFR 1000Z to 1600Z.

(3) *Icing and freezing level.* Icing none. Freezing level is sloping from near 4,000 feet in eastern Tennessee to near 12,500 feet in Arkansas and coastal waters.

16-4. Terminal Forecast

a. General. Terminal forecasts (FT) (fig 16-5, 16-6, and 16-7) are prepared daily by civil and military aviation terminals. National Weather Service terminal forecasts are issued three times daily at 1000Z, 1500Z, and 2200Z and will have a 24-hour forecast validity period. The last 6 hours of the 24 will be a categorical forecast using the same contractions as found in the area forecasts (FA) (fig 16-3). The Navy uses the Plain Language Terminal Forecast (PLATF) code in the United States (fig 16-6). The Navy forecasts are prepared every 6 hours and are valid for 24-hour periods with a new line shown for each forecast change. The terminal forecast used by the Air Force (Fig 16-7) consists of a 6-hour local forecast (called *recovery forecast*) made up by the various Air Weather Service Offices, supplemented by a 20-hour followup forecast (called the *scheduling forecast*) prepared by the Global Weather Central (GWC) facility at Offutt AFB, Nebraska. The locally prepared re-

	<u>WSFO Locations</u>	<u>Area of Forecast Responsibility</u>
DFW	Fort Worth -----	New Mexico, Oklahoma, Texas, coastal waters.
BOS	Boston -----	New England, New York, Pennsylvania, adjacent Great Lakes, New Jersey, coastal waters.
CHI	Chicago -----	Minnesota, Iowa, Missouri, Illinois, Michigan, Lake Michigan and U.S. Portions of Lakes Superior and Huron, Indiana, Wisconsin, Kentucky.
WBC	Washington -----	West Virginia, Ohio, Adjacent Great Lakes, Maryland, Delaware, District of Columbia, Virginia, North Carolina, South Carolina, coastal waters.
MIA	Miami -----	Florida east of 85 degrees, coastal waters, Georgia.
MKC	Kansas City -----	Wyoming, Colorado, Nebraska, Kansas, North Dakota, South Dakota.
MSY	New Orleans -----	Alabama, Arkansas, Louisiana, Mississippi, Florida west of 85 degrees, coastal waters, Tennessee.
SFO	San Francisco -----	California, Oregon, Washington, coastal waters.
SLC	Salt Lake City -----	Montana, Idaho, Nevada, Utah, Arizona.

OUTSIDE CONTERMINOUS U.S.

Anchorage -----	Alaska including Alaskan Peninsula.
Honolulu -----	Hawaiian Archipelago
San Juan -----	Caribbean and Atlantic east of 72 degrees W.

Figure 16-1. Aviation area forecast location.

<u>ISSUANCE TIMES</u>	<u>VALIDITY PERIODS</u>
1240Z	1300Z-0700Z
0040Z	0100Z-1900Z

Figure 16-2. Area forecast transmittals.

covery forecast is transmitted using a plain language code (PLATF) almost identical to the Navy PLATF; the scheduling forecast from Global Weather Central uses an International Terminal Aerodrome Forecast (TAF) code which is like the METAR code described in chapter 11.

b. *Interpretaton of Terminal Forecast, National Weather Service (Fig 16-5).* Station identification is followed by the date and valid time of the forecast in whole hours Zulu. Sky conditions are forecast in hun-

<u>CONTRACTIONS</u>	<u>DEFINITION</u>	<u>CEILING</u>	<u>CRITERIA</u>	<u>VISIBILITY</u>
LIFR	LOW INSTRUMENT FLIGHT RULES	< 500	AND/OR	< 1
IFR	INSTRUMENT FLIGHT RULES	< 1000 FT.	AND/OR	< 3 MILES
MVFR	MARGINAL VISUAL FLIGHT RULES	≥ 1000 TO	≤ 3000 AND/OR	≥ 3 TO ≤ 5
VFR	VISUAL FLIGHT RULES	> 3000	AND	> 5

Figure 16-3. Categorical outlook criteria.

MSY FA 301240
13Z FRI-07Z SAT
OTLK 07Z-19Z SAT

TENN ARK LA MISS ALA FLA W OF 85 DEGS CSTL WTRS

HGTS ASL UNLESS NOTED

SYNOPSIS. A STG HI PRES RDG COLUMBUS GA SWWD TO LAKE CHARLES LA WL MOV SLOLY SWD. A CDFNT WITH NO ASSOCIATED SIG CLDS AND WX ACRS MICHIGAN SWWD TO NEBRASKA WL MOV SEWD RCHG A DYERSBURG TENN TO CHATTANOOGA TENN LN BY 07Z.

SIGCLDS AND WX

OVR AREA A FEW PTCHS VSBY BLO 3GFKH TIL 15Z OTRW NO SIGCLDS AND WX. OTLK VFR XCPT MVFR 10Z-16Z.

ICG. NONE. FRZLVL SLPG FM NR 40 ERN TENN TO NR 125 ARK AND 125 CSTL WTRS.

Figure 16-4. Area forecast.

dreds of feet in ascending order with the bases above ground level in hundreds of feet. Forecast ceilings are preceded by the letter "C." Visibilities expected to exceed 8 statute miles are omitted, as are winds below 10 knots. The times of expected significant changes are indicated in the body of the forecast in whole hours Zulu.

(1) *Circuit heading.* In the circuit heading (fig 16-5), the FT is the identifier for terminal forecasts. The date and time group that follows is the time of transmission to the nearest minute Zulu. The stations listed are those for the basic circuit area. The lower groups consist of selected stations around the basic circuit area listed by state in the same manner as the civil teletype reports in chapter 11.

(2) *Forecast for Montgomery, Alabama (MGM).* The forecast is on the 19th day of the month and is valid between 1500Z the 19th and 1500Z the 20th. Conditions expected at the beginning of the period are 1,000 feet scattered, 25,000 feet thin broken with 5 miles visibility in haze and smoke, scattered variable broken. At 1700Z they expect ceiling 3,000 feet broken (broken variable scattered) with a chance of a ceiling 1,000 feet overcast, visibility 2 miles and thunderstorms and rain showers. At 0300Z, the forecast is for 25,000 feet thin broken with a slight chance of rain

showers or thunderstorms and rain showers. At 0900Z, the categorical forecast is VFR becoming MVFR with ground fog.

(3) *Forecast for Albany, Georgia (ABY).* This forecast is for a ceiling 800 feet broken. At 1700Z, they expect a ceiling 3,500 feet broken, wind from 090° at 10 knots, broken variable scattered with a chance of ceiling 800 feet obscured, visibility ½ mile with thunderstorms and rain showers. By 0200Z, the forecast is clear. At 0800Z, the forecast is ceiling 500 feet broken with chance of ceiling 200 feet obscured, ¼ mile visibility and fog. The last 6 hours of the period beginning 0900Z is forecast as IFR with ceilings caused by fog.

c. *Interpretation of Terminal Forecast, Navy (Fig 16-6).* The interpretation of the Navy terminal forecast is similar to that of the National Weather Service forecast (b above). Clouds are forecast in ascending order with the predominant or most general cloud cover condition included in the main text and variable conditions listed under modifying remarks. The visibility and winds have no restriction, and the peak speed of gusts will follow the letter "G." A new line will be used for change periods and the following terms may apply in defining the changeable weather conditions: GRADU, RAPID, TEMPO, and INTER

FT 191440
 MGM 191515 10SCT 250-BKN 5HK SCT V BKN. 17Z C30BKN BKN V SCT
 CHC C100VC 2TRW. 03Z 250-BKN SLGT CHC RW/TRW. 09Z VFR BCMG MVFR GF..
 PNS 191515 10SCT 250-BKN SCT V BKN. 17Z C30 BKN CHC C80VC 1TRW.
 04Z 100SCT 250-BKN SLGT CHC RW/TRW. 09Z VFR BCMG MVFR GF..
 TCL 191515 15SCT 250-BKN 5GF SCT V BKN. 17Z C30BKN CHC C100VC 1TRW+.
 04Z 250-BKN SLGT CHC RW/TRW. 09Z MVFR GF..
 BHM 191515 15SCT 250-BKN 5KH SCT V BKN. 17Z C30BKN CHC C100VC 2TRW.
 04Z 250-BKN SLGT CHC RW/TRW. 09Z MVFR GFK..
 MSL 191515 C30BKN 100BKN LWR BKN OCNL SCT CHC C100VC 1TRW AFT 17Z.
 04Z 100SCT 5GFK. 09Z MVFR GFK..
 ANB 191515 15SCT 250-BKN. 17Z C30BKN BKN V SCT CHC C100VC 2TRW.
 04Z 250-BKN SLGT CHC RW/TRW. 09Z MVFR GF..
 ATL 191515 C15BKN. 17Z C35BKN 0710 BKN V SCT CHC C8X 1/2TRW. 02Z CLR.
 08Z C5BKN CHC C2X 1/4F. 09Z IFR CIG F..
 DHN 191515 10SCT 250-BKN 5GF. 17Z C30BKN BKN V SCT CHC C100VC 2TRW.
 03Z 250-SCT. 09Z VFR BCMG MVFR GF..

ALABAMA 191442

HSV 191515 20SCT 250-BKN SCT V BKN. 17Z C30BKN CHC C100VC 2TRW.
 04Z 100SCT 5H. 09Z MVFR GF..
 MOB 191515 10SCT 250-BKN 5H SCT V BKN. 17Z C30BKN CHC C80VC 1TRW.
 04Z 100SCT 250-BKN SLGT CHC RW/TRW. 09Z VFR BCMG MVFR GF..

GEORGIA 191442

ABY 191515 C8BKN. 17Z C35BKN 0910 BKN V SCT CHC C8X 1/2TRW. 02Z CLR.
 08Z C5BKN CHC C2X 1/4F. 09Z IFR CIG F..
 AGS 191515 C15BKN. 17Z C35BKN 1210 BKN V SCT CHC C8X 1/2TRW. 02Z CLR.
 06Z C5BKN CHC C2X 1/4F. 09Z IFR CIG F..
 AHN 191515 C15BKN. 17Z C35BKN 0710 BKN V SCT CHC C8X 1/2TRW. 02Z CLR.
 06Z C5BKN CHC C2X 1/4F. 09Z IFR CIG F..
 MCN 191515 C8BKN. 17Z C35BKN 0910 BKN V SCT CHC C8X 1/2TRW. 02Z CLR.
 07Z C5BKN CHC C2X 1/4F. 09Z IFR CIG F..
 SAV 191515 15SCT C30BKN 0910 LYRS SCT V BKN OCNL C8X 1/2RW/TRW.
 09Z MVFR CIG RW..

Figure 16-5. Terminal forecast, National Weather Service.

(table 16-1). The forecast of the minimum altimeter setting will follow an identifier QNH.

(1) In the circuit heading (fig 16-6), 273 is the geographical circuit area number, KAWN means the communication is from the automated weather network facility at Carswell AFB, Texas, 15 is the day of the current month, and 0900 is the time of transmission in hours and minutes Zulu.

(2) The first line listing for each station includes the identifier (fig 16-6), the contraction PLATF (which means plain language terminal forecast) and the date followed by the valid 24-hour forecast pe-

riod. The valid time for this forecast is between 0900Z one day and 0900Z the following day. At 0900Z, KNQA (Memphis NAS, Tennessee) forecasts scattered clouds to exist at 1,500 feet with a broken sky cover at 3,000 feet; visibility will be 6 miles with haze; wind is forecast to be from the northwest at 12 knots; altimeter 30.09 inches of mercury. At 1200Z, scattered clouds will exist at 3,000 feet; visibility will be 3 miles with ground fog and haze; wind is again forecast to be from the northwest at 12 knots; altimeter 30.10 inches of mercury. By 1600Z, the forecast is for clear skies with a visibility of 7 miles; wind from 320° at 15 knots


```

FTUS 273 KAWN 150900

KNQA PLATF 150909
KNQA 15SCT 30BKN 6H 3112 QNH 3009
    12Z 30SCT 3GFH 3112 QNH 3010
    16Z CLR 7 3215G25 QNH 3012

KNMM PLATF 150909
KNMM 200VC 7 QNH 3007
    12Z 25SCT 7 3206 QNH 3010
    16Z 25SCT 7 3408 QNH 3014
    20Z CLR 7 3412 QNH 3020

KNPA PLATF 150909
KNPA CLR 7 3412 QNH 3005
    17Z 250SCT 3416 QNH 3018
    01Z CLR 7 3412 QNH 3018

KNAB PLATF 150909
KNAB 35BKN 250BKN 3GF 2705
    TEMPO 1113 -X35BKN 250BKN 1GF 2705
    14Z 35BKN 250BKN 7 2908 BKN V SCT
    22Z 250VC 7 3010G15 QNH 2994

```

Figure 16-6. Terminal forecast, Navy.

Table 16-1. Changeable Weather Conditions

Gradual Changes—GRADU is used if the change(s) is (are) expected to take place at an approximately constant rate throughout the period. "GRADU 0204" indicates a gradual change between 0200 and 0400 GMT.

Rapid Changes—RAPID is used when the change(s) is (are) expected to take place during a period lasting less than half an hour.

Temporary Changes—TEMPO is used if the change(s) is (are) expected to last for a period of less than one hour in each instance and changes take place throughout the period. "TEMPO 1521" indicates a temporary change (or changes) between 1500 and 2100 GMT.

Intermittent Changes—INTER is used if the change(s) is (are) expected to occur frequently for short periods of time, the conditions fluctuating almost constantly, throughout the period. "INTER 0913" indicates intermittent changes between 0900 and 1300 GMT.

with gusts to 25 knots; altimeter 30.12 inches of mercury.

(3) The forecast for KNAB (Albany NAS, Georgia) at 0900Z (fig 16-6) is 3,500 feet broken, 25,000 feet broken with 3 miles visibility and ground fog, wind from 270° at 5 knots. A temporary condition is forecast between 1100Z and 1300Z. From time to time during that period they expect a partial obscuration to exist with a broken condition at 3,500 feet and 25,000 feet; visibility to be 1 mile in ground fog with wind from 270° at 5 knots. By 1400Z, they expect:

3,500 feet broken, 25,000 feet broken, 7 miles visibility, wind from 290° at 8 knots with cloud layer broken varying to scattered. At 2200Z, the sky condition should be 25,000 overcast with 7 miles visibility, wind to be from 300° at 10 knots with gusts to 15 knots. The lowest altimeter setting expected is 29.94 inches of mercury.

d. Interpretation of Terminal Forecast, Air Weather Service. In the circuit heading (upper part of fig 16-7) FCUS is the identifier for the military recovery forecast prepared by the individual Air Weather Service facilities, 46 is the circuit area number; KAWN means the communication is relayed through the automated weather network facility at Carswell AFB, Texas; 01 is the day of the current month; and 0101 is the time of transmission to the nearest minute Zulu. FTUS (lower part of fig 16-7) is the indicator for military terminal forecast designed as a 20-hour followup to the recovery forecast above. This forecast, called a scheduling forecast, covers the same facilities in circuit 46 and is prepared by Global Weather Central (KGWC) at Offutt AFB, Nebraska. The date time group indicates date of current month and time of transmission to the nearest minute Zulu.

(1) *Recovery forecast (FCUS) for Tinker AFB, Oklahoma (KTIK) (upper part of fig 16-7).* The station identifier is followed by the valid period shown as 0105 indicating whole hours Zulu. The 0105Z forecast following the identifier (KTIK) shows the expected

FCUS 46 KAWN 010101
 KTIK 0105 8BKN 400VC 7R- 1608 02Z 8SCT 400VC QNH 2938
 05Z 40BKN 1000VC LAST NO AMENDS AFT 0100Z
 KLTS 0105 5SCT 25SCT 1000VC 10 1810 QNH 2938
 INTER 5SCT 250VC 3RW- TRW VCNTY
 05Z 10SCT 25SCT 1000VC 7 3315G25 25SCT V BKN OCNL
 RW- TRW VCNTY

FTUS 46 KGWC 010315

KTIK 0501 16008 9999 6SC040 8AS100 QNH 2938INS CIG040 OCNL RA
 TS VCNTY
 GRADU 0607 29012/20 9999 5SC040 8AS100 QNH 2934INS
 CIG040 CB VCNTY
 GRADU 0910 33010/18 9999 3SC030 5AC080 3C1250 QNH 2940INS
 CIG080
 GRADU 1415 34014 9999 3SC040 3AC100 QNH 2950INS CIG 100 0
 KLTS 0501 33015/25 9999 2CU010 2CU025 8AS100 QNH 2983INS CIG 100
 OCNL RA TS VCNTY
 GRADU 0809 33010/22 9999 2CU050 2AC130 4C1250 QNH 2942INS
 CIG250
 GRADU 1415 33013 9999 2CU050 2AC130 4C1250 QNH 2952INS
 CIG250 0
 KFSI 0501 33012/22 9999 2ST010 5SC030 8AS100 QNH 2953INS CIG030
 TS VCNTY
 GRADU 0910 34012/22 9999 3SC030 5AC080 3C1250 QNH 2942INS
 CIG080 CB VCNTY
 GRADU 1718 33012 9999 2AC100 2C1250 QNH 2955INS
 NO RECOVERY FCST AVAILABLE 0

Figure 16-7. Terminal forecast, Air Weather Service.

weather to be 800 feet broken, 4,000 feet overcast; visibility of 7 miles with light rain. Wind is forecast to be from 160° at 8 knots. At 0200Z, they expect a scattered condition at 800 feet and an overcast condition at 4,000 feet; the lowest altimeter setting is forecast to be 29.38 inches of mercury. By 0500Z, the conditions should be 4,000 feet broken and 10,000 feet overcast, with the note that this will be the last forecast for that day with no amendments after 0100Z.

(2) *Terminal forecast (FTUS) for Tinker AFB, Oklahoma (KTIK).* The terminal forecast (scheduling) makes use of the international terminal aerodrome forecast (TAF) code which is similar to the METAR code of chapter 11. The station identifier (KTIK) is followed by the valid forecast period (0501) 0500Z to 0100Z which follows the 4-hour recovery forecast ((1) above). *Reading these in combination gives the standard 24-hour forecast coverage for each station.* In the sample forecast for KTIK (fig 16-7), at 0500Z they expect the following: the wind to be from 160° at 8 knots; visibility 10,000 meters or greater; six-eighths of the sky covered with stratocumulus with bases at 4,000 feet; eight-eighths cover of altostratus with bases of 10,000 feet; altimeter setting 29.38 inches of mercury with the ceiling 4,000 feet. Remarks indicate occasional rain and thunderstorms in the vicinity. From 0600Z to 0700Z, they expect gradual changes to the following: wind 290° at 12 knots with gusts to 20 knots, visibility 10,000 meters or greater, five-eighths of sky covered by stratocumulus based at 4,000 feet, with eight-eighths of sky covered by altostratus based at 10,000 feet, altimeter 29.34 inches of mercury. Ceiling at 4,000 feet with cumulonimbus in the vicinity. In the period from 0900Z to 1000Z, they forecast gradual changes to: wind 330° at 10 knots with gusts to 18 knots, visibility 10,000 meters or greater, three-eighths stratocumulus at 3,000 feet, five-eighths altocumulus at 8,000 feet, three-eighths cirrus at 25,000 feet, altimeter to be 29.40 inches with the ceiling at 8,000 feet. Between 1400Z and 1500Z, they expect a gradual change to: wind 340° at 14 knots, visibility 10,000 meters or greater, three-eighths altocumulus at 10,000 feet, altimeter 29.50 inches of mercury with a ceiling at 10,000 feet. Scattered symbol ☉ is used to show end of forecast.

16-5. Winds Aloft Forecasts

a. *General.* Winds and temperature aloft forecasts (FD) (fig 16-8) are computer prepared and issued by the National Meteorological Center at Suitland, Maryland. This data is transmitted to both civil and military weather stations through the Weather Message

Switching Center, Kansas City, Missouri. The forecasts are valid 12 (FD1), 18 (FD2), and 24 (FD3) hours after the observation date times of 0000Z and 1200Z upon which they are based. An unscheduled amendment to an FD may be prepared and issued by a WSFO.

b. *Levels Forecasts.* Dependent upon station elevation, wind forecasts are issued for the following levels: 3-, 6-, 9-, 12-, 18-, 24-, 30-, 34-, and 39-thousand-foot levels. The first level for which a wind forecast is issued is at least 1,500 feet above the station elevation. Temperature is forecast for all wind levels (except the 3,000-foot level) that are 2,500 feet or more above the station. The minus signs are deleted preceding the temperatures at the 30-, 34-, and 39-thousand-foot levels.

Type	Base Date, Time	Valid	For use (period)
FD1	0000Z	1200Z	0600-1400Z
FD2	0000Z	1800Z	1500-2100Z
FD3	0000Z	0000Z	2100-0300Z *
FD1	1200Z	0000Z	1800-0300Z
FD2	1200Z	0600Z	0300-0900Z #
FD3	1200Z	1200Z	0900-1500Z #

* At 1800Z, discontinue using FD forecasts based on 0000Z data if new forecasts based on 1200Z data are available
At 0600Z, discontinue using FD forecasts based on 1200Z data if new forecasts based on 0000Z data are available

c. *Direction.* The wind direction is in reference to true north and is reported in two digits, except as noted in d below. *For example,* 270° is reported as 27.

d. *Speed.* The windspeed is reported in knots. Speeds less than 10 knots are shown as 08, 06, and similar groups. If the speed is expected to be less than 5 knots, the group "9900" is inserted instead of the direction and speed. This group is spoken of as "light and variable." Forecast winds of 100 to 199 knots are indicated by subtracting 100 from the speed and adding 50 to the first two digits of the direction indicator. *For example,* a forecast of 250°/145 knots would be reported as 7545.

e. *Amended FD.* An amended FD is distributed to the same circuits as the original FD and shall be prepared by civil and military forecast offices as shown in the following example:

CAE FD3 172020
DATA BASE 171200Z
VALID 181200Z
FT 3000 6000 9000
CAE 1008 2710-08 2715-10

FDUS3 KWBC 171945									
DATA BASED ON 171200Z									
VALID 181200Z FOR USE 0900-1500Z. TEMPS NEG ABV 24000									
FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
ABI	2412-01	2314-06	2215-12	2324-25	2434-36	255147	255646	255949	
AMA	2810	2713-06	2507-13	9900-25	0805-37	050549	990052	261851	
ATL 1312	1911-06	2314-09	2521-12	2644-21	2669-30	269542	760749	279752	
BHM 1511	1912-06	2215-08	2420-12	2543-20	2667-30	269342	760549	279450	
BNA 1711	2210-07	2414-10	2519-14	2637-24	2657-33	268645	760051	278951	
BRO 9900	2512+07	2620+02	2627-03	2657-14	2693-24	762837	762645	761453	
CAE 0910	9900-08	2710-10	2620-13	2746-21	2673-30	770241	771249	770853	
CLE 2416	2722-10	2763-14	2723-18	2829-29	2935-40	294152	294453	284452	
CRP 0806	1912+06	2216+00	2421-05	2557-17	2693-27	762840	762345	760450	
CRW 2206	2711-09	2815-13	2820-17	2837-27	2755-37	277949	278552	277852	
DAL 0909	2407-02	2111-07	2016-12	2228-24	2338-35	256547	257148	257150	

Figure 16-8. Winds aloft forecast.

Section III. FASCIMILE PROGNOSTIC CHARTS

16-6. Surface Prognostic Charts

a. A major function of the National Meteorological Center is to provide field weather stations with forecasts (prognoses) of surface conditions. These forecasts are used as forecasting aids at local weather stations. The local forecast remains the responsibility of the individual issuing it. The objective of NMC prognoses is to forecast the major anticipated weather changes. Individual weather stations should make local refinements to NMC prognoses.

b. NMC forecasts are transmitted over facsimile circuits to local weather stations. The basic 12- and 24-hour prognosis is transmitted as a group of four charts (fig 16-9) approximately four times a day. The two upper charts are called low level significant weather prognoses and portray the significant weather from the surface to the 400-millibar (mb) level in the same manner as the Weather Depiction Chart covered in paragraph 12-4. Areas forecast to be IFR are enclosed by a solid line, those expected to be MVFR are enclosed by a scalloped line. Additionally, areas expected to have moderate or greater turbulence are enclosed in a dashed solid line and will include turbulence symbols (fig 16-10) with vertical extent in hundreds of feet. Dotted and dashed lines show location of the freezing level both at the surface and aloft.

c. The lower two charts (fig 16-9) give the surface prognosis for 12 and 24 hours and show expected position and orientation of fronts, pressure systems,

and areas of continuous and showery type precipitation. Fronts are shown using standard symbols (para 12-2d(1)) and are coded as to type and intensity. Highs (H) and lows (L) are shown with their pressure labeled in tenths and units of millibars. Forecast movement of the pressure centers is normally indicated by an arrow with speed given in knots. Symbols are used to show forecast precipitation areas (fig 16-10) with continuous precipitation areas encircled with a solid line and showery type precipitation enclosed with a dot-dash line. Verifying times of these charts are shown at the lower left. Local weather station personnel will normally add color to these charts to highlight the features for easier interpretation.

d. Another facsimile chart is the 36- and 48-hour surface prognosis (fig 16-11). These charts are slightly different from the 12- and 24-hour charts discussed above. On the 36- and 48-hour prognosis, the expected isobar patterns are shown and are drawn at 8-millibar intervals and labeled in multiples of eight. (Occasionally intermediate isobars (dashed lines) are shown to show pattern continuity.) Scalloped lines on these charts enclose areas where an overcast cloud cover or an overcast with a few breaks is expected to occur at the verifying time (VT) of the prognosis. Stippled areas indicate expected 50% or more coverage of precipitation with continuous type encircled with a solid line and showery precipitation enclosed by a dot-dash line, at the verifying time. These charts will include a prognostic discussion of the data at the lower part of the chart.

112-9

— 8-73

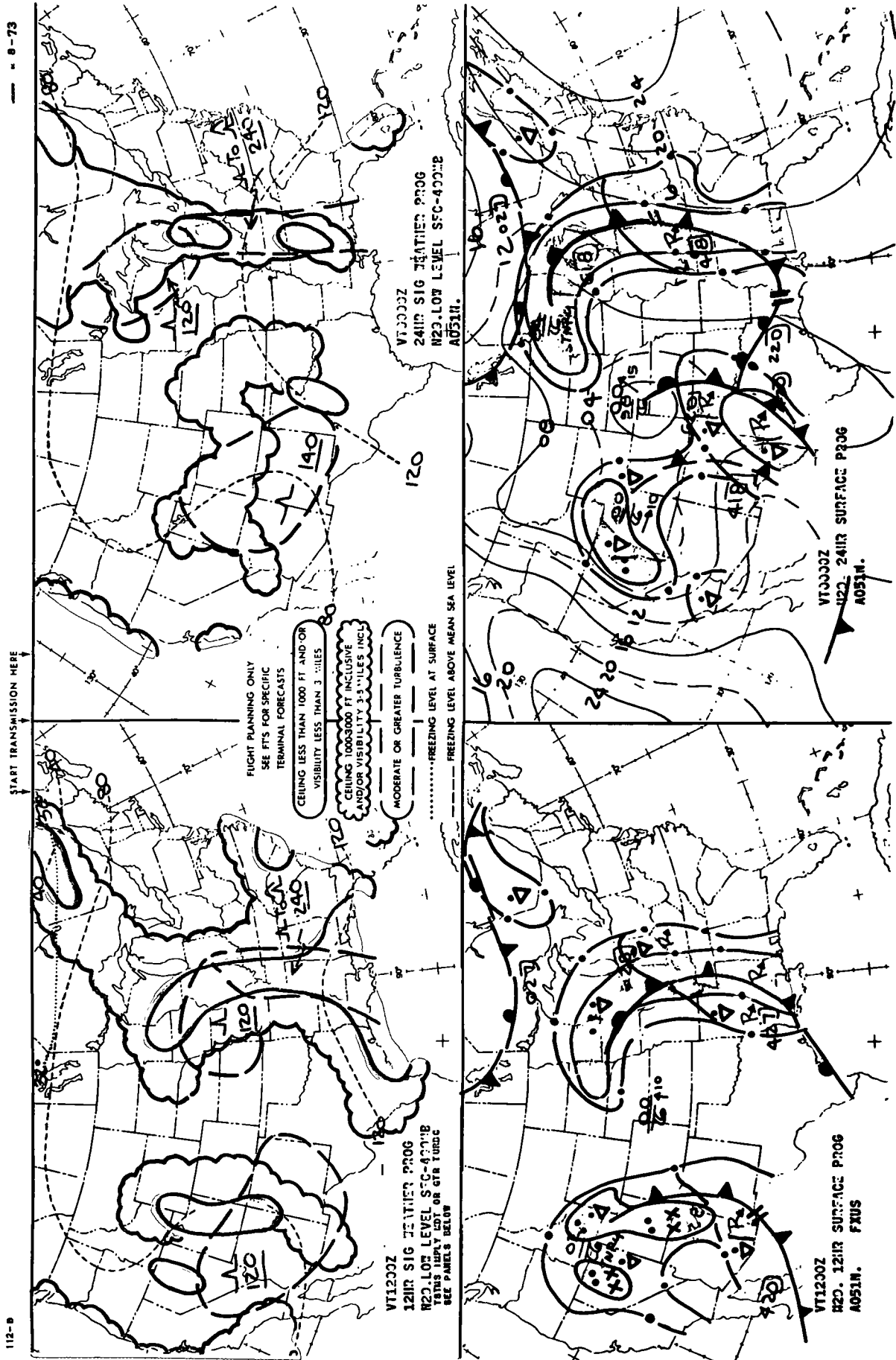


Figure 16-9. A 12- and 24-hour surface prognosis.

• •	RAIN
▽	RAIN SHOWERS
▽*	SNOW SHOWERS
≡	FOG
△	HAIL
⚡	THUNDERSTORMS
↻	BLOWING SAND OR DUST
→	BLOWING (DRIFTING) SNOW
△	ICE PELLETS (SLEET)
~	FREEZING RAIN
✕	RAIN AND SNOW (MIXED)
ψ	LITE RIME ICING
ψ	MOD RIME ICING
ψ	SVR RIME ICING
∧	LITE CLEAR ICING
∧	MOD CLEAR ICING
∧	SVR CLEAR ICING
∧	LITE TURBULENCE
∧	MOD TURBULENCE
∧	SVR TURBULENCE

Figure 16-10. Symbols for weather elements.

16-7. Constant-Pressure Prognostic Charts

a. Facsimile forecast charts of upper-air conditions are called *constant-pressure prognostic charts*. Approximately 20 of these charts are transmitted by the NMC each day for altitudes up to 300 millibars and for periods of time up to 72 hours. Charts drawn

for altitudes below 300 millibars usually consist of contour lines and labeled centers of high (H) and low (L) elevation. Constant-pressure prognostic charts at and above 300-millibar altitudes normally include additional data for jet stream axes and wind speed (isotachs).

b. The 36-hour 700-millibar prognostic chart (fig 16-12) is convenient for flight planning at altitudes near 10,000 feet. The contour lines on this chart are drawn and labeled at 60-meter intervals.

c. Since the wind flows parallel to the contour lines at a speed directly proportional to the distance between contours (chap 14), values for wind direction and speed may be computed from constant-pressure prognostic charts. Weather conditions on the charts depict the conditions expected at the specified verifying time (VT), rather than the average weather conditions expected between transmission time and verifying time.

16-8. Upper-Wind Prognosis Charts

The 12-hour upper-wind prognosis charts provide a map-like portrayal of the forecast winds similar to the winds aloft charts discussed in paragraph 13-8. There are eight charts in this series which are transmitted twice a day (fig 16-13). These charts provide forecast winds and temperatures for 6000, 9000, 12000, 18000, 24000, 30000, 34000, and 39000 feet. Winds are plotted using the barb and pennant system described in paragraph 13-8, with temperatures in degrees Centigrade.

16-9. Other Prognostic Charts

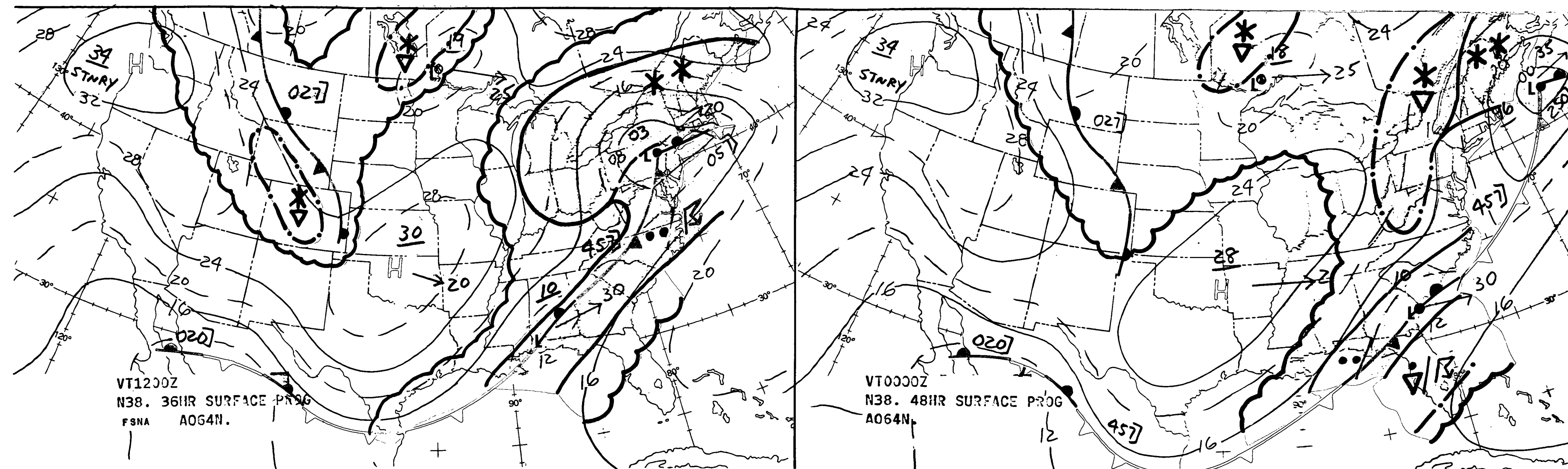
Other commonly available prognostic charts of surface and upper-air weather conditions include—

a. Twenty-four- and thirty-six-hour vertical velocity prognosis.

b. Five-day forecast charts for the surface.

c. Thirty-day outlook charts covering the 700-millibar contours, regional surface temperatures, and precipitation areas.

d. High-level significant weather prognosis to include maximum wind and wind shear.



Prog Discussion from 0000Z, Feb. 6, 1974, data:
Re Fax N29 and 38

LFM and PE progs were based on only limited amount of sfc and upr air data. 195 computer was used today.

Nwrn US conts to be protected by qstnry rdg alf nr cst therefore ltl chg in sfc pat expcd. Pres as fcst by LFM and PE sfc progs ovr most of US looks too low in view of initial values and pres chg data. Low lvl cold air push swd ovr

cntrl Plains is contg and this will help cause sfc low to organize ovr Mo soon. Guidance progs acptd on dpng and ewd movt of this low. Pbly by 36 hr this low will be redvlpng alg the wrm front fcst to be S of New Eng. RH progs look like good guidance for pcpn area nern US. Convective pcpn should form alg and ahd of front as it movs thur sern US. Smith

Figure 16-11. A 36- and 48-hour surface prognosis.

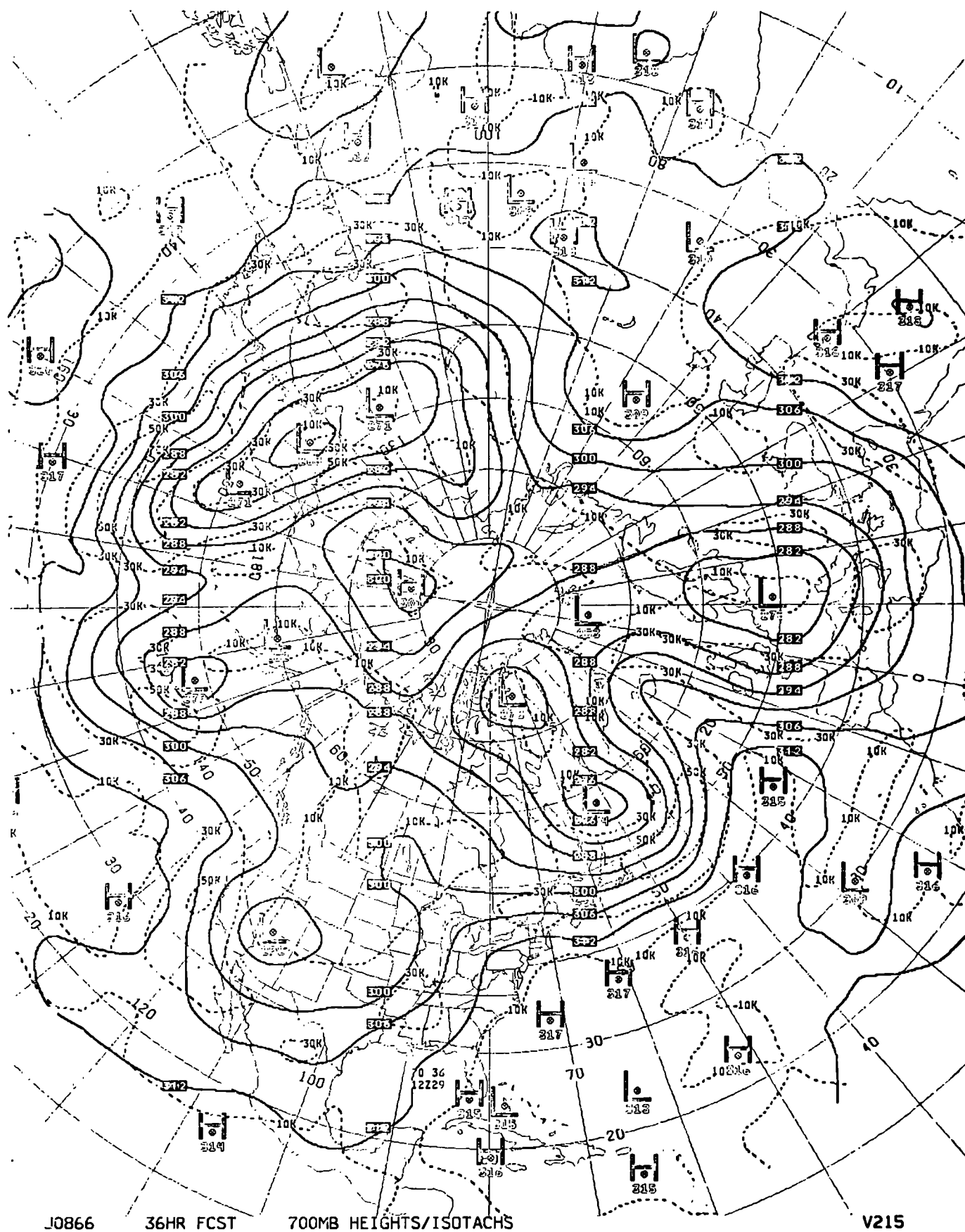


Figure 16-12. A 36-hour 700-millibar prognostic chart.

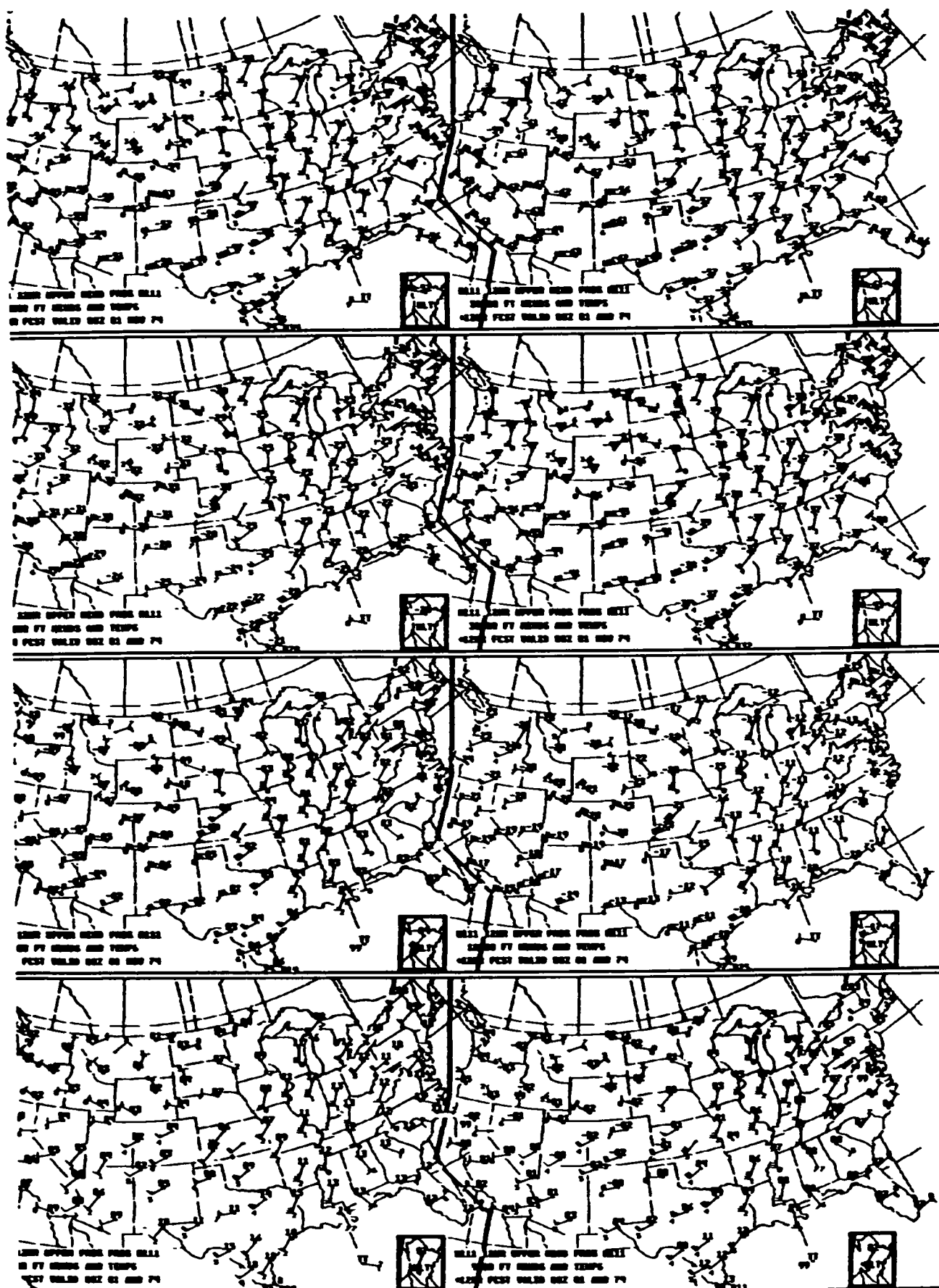


Figure 16-13. Upper-wind prognosis chart.

CHAPTER 17

WEATHER FLIGHT PLANNING

Section I. PREFLIGHT PLANNING

17-1. General

Effective weather flight planning requires that the aviator have a sound knowledge of basic weather principles, a thorough understanding of the weather facilities available for his use, and the ability to use the available weather data in order to complete the mission safely.

a. The amount of weather information that the aviator needs will vary with the conditions for the flight, the aircraft equipment, and aviator capabilities. The aviator planning an IFR flight is primarily interested in the ceiling and visibility conditions at point of departure, destination, and possible alternates, and the type weather he will encounter en route as it pertains to icing, turbulence, and winds aloft. Since the aviator planning a VFR flight must rely on visual references for navigation and be able to see other aircraft for separation purposes, he is more concerned with the height of cloud bases and visibility.

b. After takeoff, the aviator must continue with his weather flight planning. He must be aware of the actual weather conditions he encounters and, with the aid of in-flight weather advisories and services available to him (para 17-6 through 17-8), keep abreast of conditions which will affect his flight. His knowledge of cloud formations, pressure patterns, air flow and other weather phenomena will enable him to analyze the validity of the forecast presented him in the briefing.

17-2. Sources of Weather Briefings

The type of weather briefing available to an Army aviator is dependent on his location. The following gives a brief description of the various means for obtaining a briefing:

a. Face-to-face briefing with a forecaster at military bases having weather briefing facilities. (Facilities with part-time availability of a forecaster may be designated as satellite stations. In this situation the pilot briefs himself using a standardized pilot briefing display (fig 17-1) and calls a designated Regional Briefing Station (RBS) for a final briefing by forecaster.)

b. Face-to-face briefing with a forecaster at civil airports having a National Weather Service office.

c. Face-to-face briefing with certified weather briefers at FAA Flight Service Stations.

d. Closed circuit television briefing at military and some civil weather briefing offices.

e. Telephonic briefings from USAF/Navy weather briefing facilities (listed in FLIP) by AUTOVON or commercial call.

f. Telephonic briefings from NWS/FAA facilities by toll free leased line service, local call, or drop line.

g. Pilot's Automatic Telephone Weather Answering Service (PATWAS) and continuous Transcribed Weather Broadcast (TWEB).

Note. Army aviators are required to obtain adequate weather information prior to flight. They are encouraged to acquire this data with minimum cost to the government. Use of AUTOVON/toll free calls should be made if at all possible; however, government collect long distance calls may be made if necessary.

17-3. Requesting the Weather Briefing

Pilot action, with regard to obtaining a weather briefing, will vary depending on the availability of weather briefing services. The normal pattern for most flight planning is to call the weather station and obtain a general picture of weather conditions prior to any detailed route and altitude selection. This allows a portion of the detailed planning to be accomplished early. When ready for the weather briefing, the aviator should provide the forecaster or briefer with the following information:

a. His name. (If by phone, inform civil facilities that you are a pilot.)

b. Aircraft identification and type.

c. Departure point, destination, and alternate.

d. Type flight plan and proposed altitude.

e. Estimated time of departure and estimated time en route to destination and to alternate.

f. Intended route.

g. En route stops, if applicable, with appropriate ETA and ETD.

h. Any distinctive limitations of aircraft or mission. In those cases where the weather briefing will be obtained by telephone to an RBS/US Navy weather briefing facility and a standardized pilot briefing dis-

STANDARDIZED PILOT BRIEFING DISPLAY

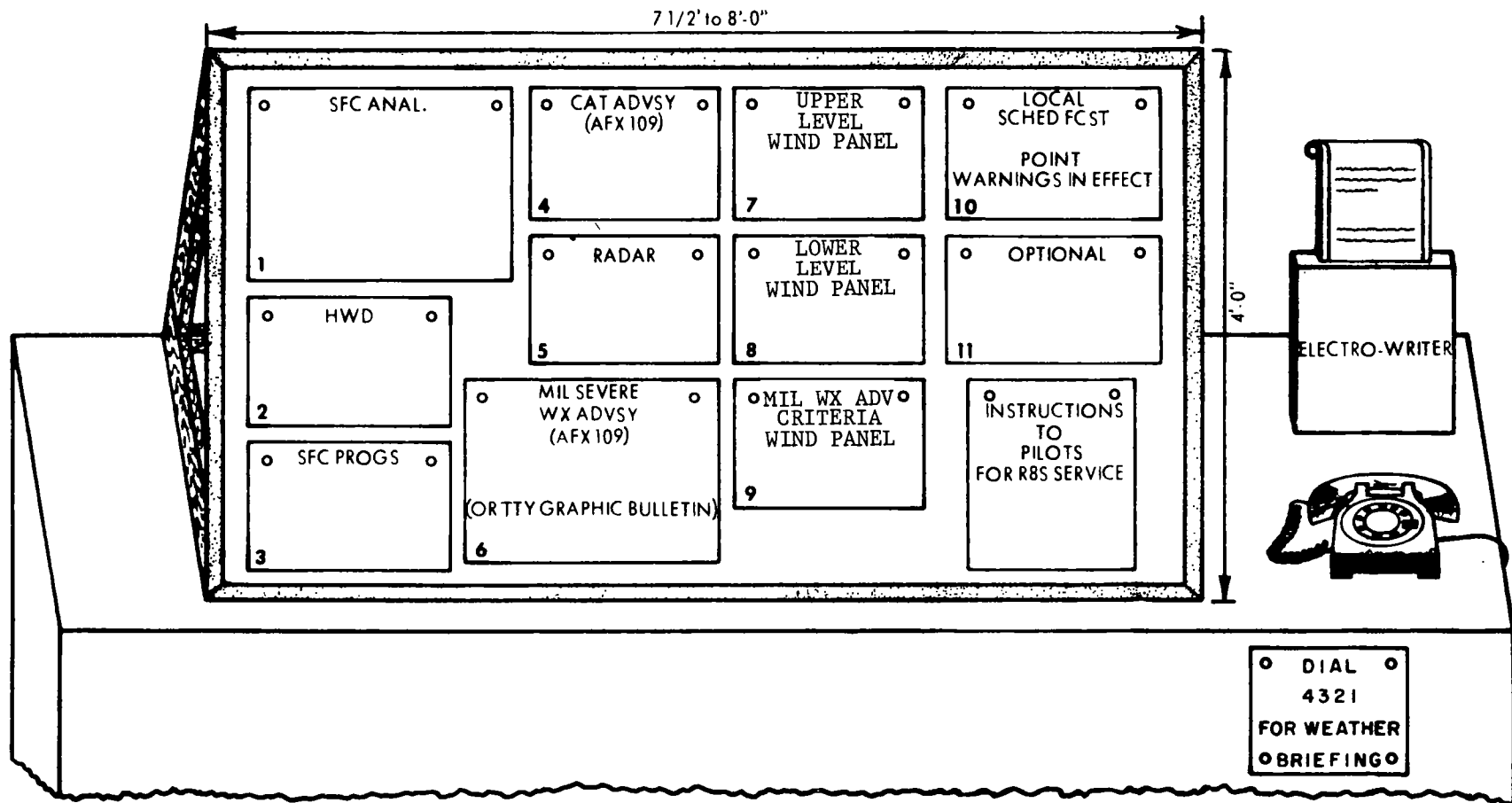


Figure 17-1. Standardized pilot briefing display.

play or similar weather data presentation is available, the pilot should brief himself (fig 17-2) to simplify the weather briefing.

17-4. Content of the Weather Briefing

The aviator should not be hesitant to ask the person giving the briefing about any particular item. The following list of key items should be checked:

a. Basic Weather.

(1) Weather at takeoff.

- Bases and tops of cloud layers.
- Visibility and obstructions to vision.
- Type and intensity of precipitation.
- Freezing level.
- Temperature and winds up to flight altitude.

ude.

- Runway temperature and density altitude.
- Condition of runways, if affected by weather.

(2) Weather en route.

- Bases, tops, types, and amount of each cloud layer.

- Visibility at the surface and aloft.
- Type, location, intensity, and direction and speed of fronts.

- Freezing level.
- Temperature and winds at various flight altitudes.

- Areas of severe weather (thunderstorms, hail, icing, and turbulence).

- Areas of good weather.

(3) Weather at destination and alternates.

- Bases, tops, types, and amount of each cloud layer.

- Visibility and obstructions to vision.
- Type and intensity of precipitation.
- Freezing level.
- Surface wind velocity.
- Condition of runways, if affected by weather.

b. Other Weather Considerations.

(1) The weather at the point of takeoff is often neglected in flight planning. Knowledge of this weather will be the deciding factor if an immediate decision must be made because of an emergency soon after takeoff.

(2) Temperatures and winds at flight altitudes must be known to compute en route times and fuel requirements.

(3) A complete picture of the ceilings, visibilities, and clouds, not only en route but for adjacent areas, will prove valuable if the aircraft malfunctions or if some other emergency forces deviation from the planned mission.

(4) A knowledge of the type and intensity of precipitation at the destination will assist the avi-

ator in estimating the runway braking action (if applicable).

(5) Obtaining all the pertinent briefing information available is a necessity in proper flight planning. Extra time expended in the weather office in forming a complete mental picture of the weather conditions could be an important factor in executing a successful mission.

Note. The decision to make a flight in adverse weather conditions is not a responsibility of the forecaster; this is a decision for the aviator and/or appropriate clearing authority.

17-5. Use of Weather Facilities

In weather flight planning, the aviator should study the various weather maps and reports either as a self-briefing or as an aid in analyzing the briefing given by the forecaster.

a. *Surface Analysis Map.* This map provides an overview of the weather. It shows the basic air mass pressure patterns with centers of high and low pressure highlighted, the different type fronts along with their surface location and frontal analysis symbols and, with the aid of local coloring, the areas of fog and precipitation. (See figure 17-3 for overview of cloud formation related to surface analysis.) These maps are plotted from the hourly sequence report observations and will generally be 1½- to 2-hours old when received over the facsimile machine. By comparing it to prior surface analysis maps, the user can see how the weather pattern has changed and, with the help of the forecaster, can envision how it will appear for his flight. The use of the weather depiction chart and latest teletype sequence reports will help complete the interpretation of weather for planning purposes. See chapter 12 for additional coverage.

b. *Weather Depiction Chart.* Since the weather depiction chart is a ready reference to areas having VFR, marginal VFR, and IFR weather conditions, it is a valuable tool for weather planning. Frontal positions and squall lines from the preceding surface analysis are shown along with major high and low pressure centers and their direction and speed of movement.

c. *Low Level Prognostic Charts.* The surface prognostic charts (chap 16) provide forecasts of significant weather at the surface and of clouds and precipitation up to the 400-millibar (approximately 24,000 feet) level. These charts are similar to the weather depiction chart but are 12- and 24-hour forecasts that include data as to freezing level and areas of moderate or greater turbulence.

SELF WEATHER PREBRIEF

This checklist is designed as an aid if no forecaster is available at the departure base but current charts and teletype are displayed. The aircrew member should:

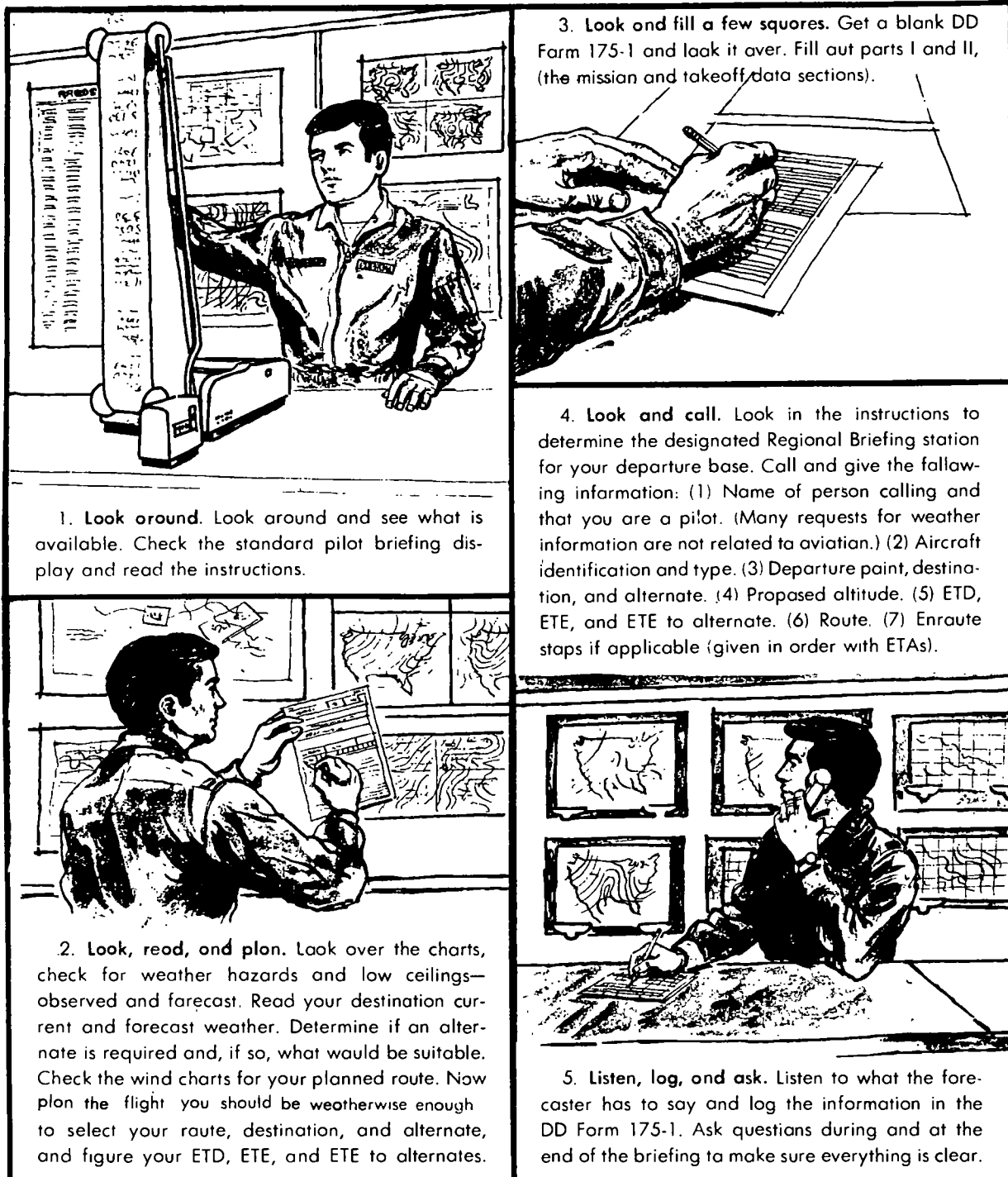
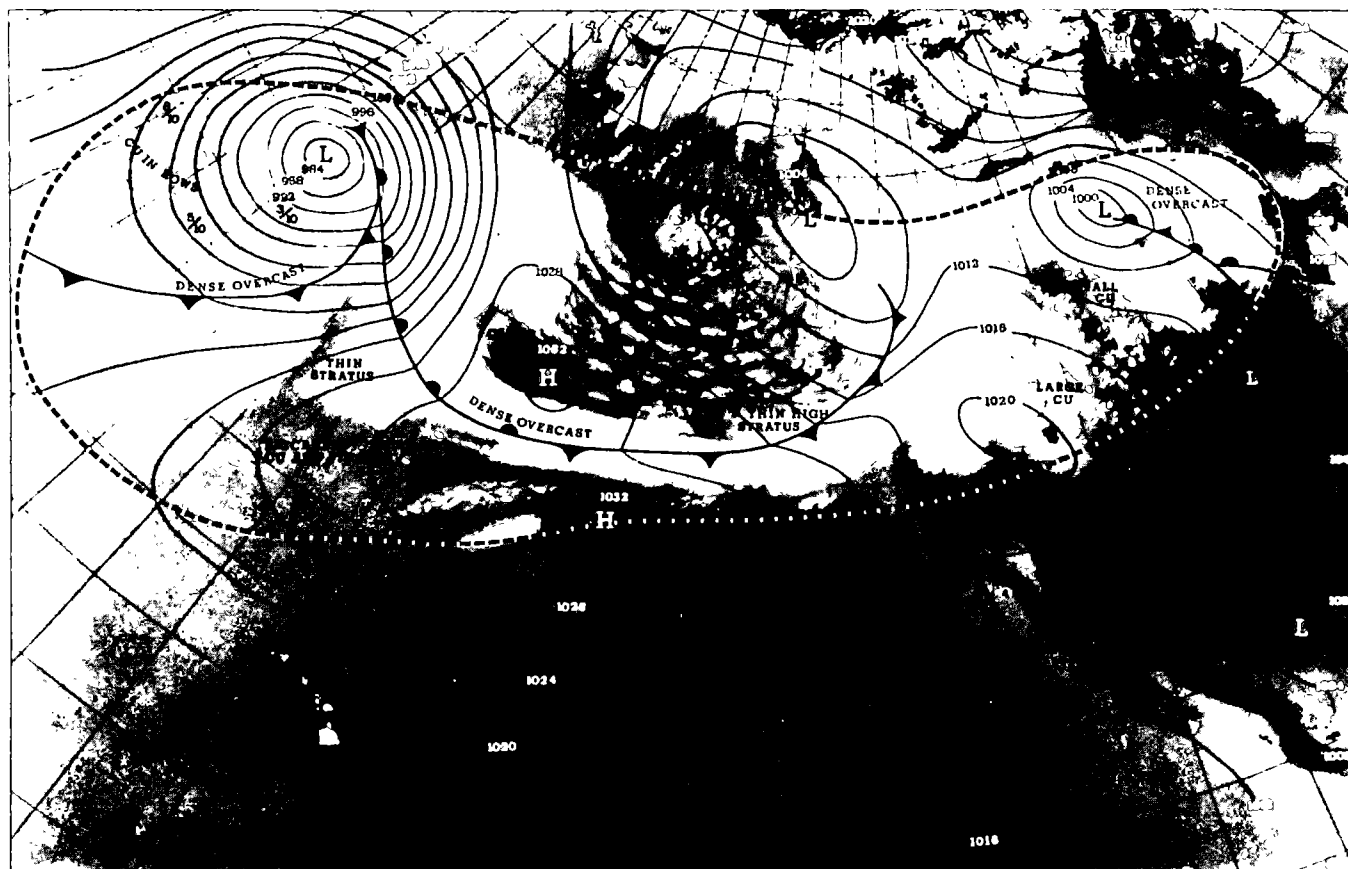
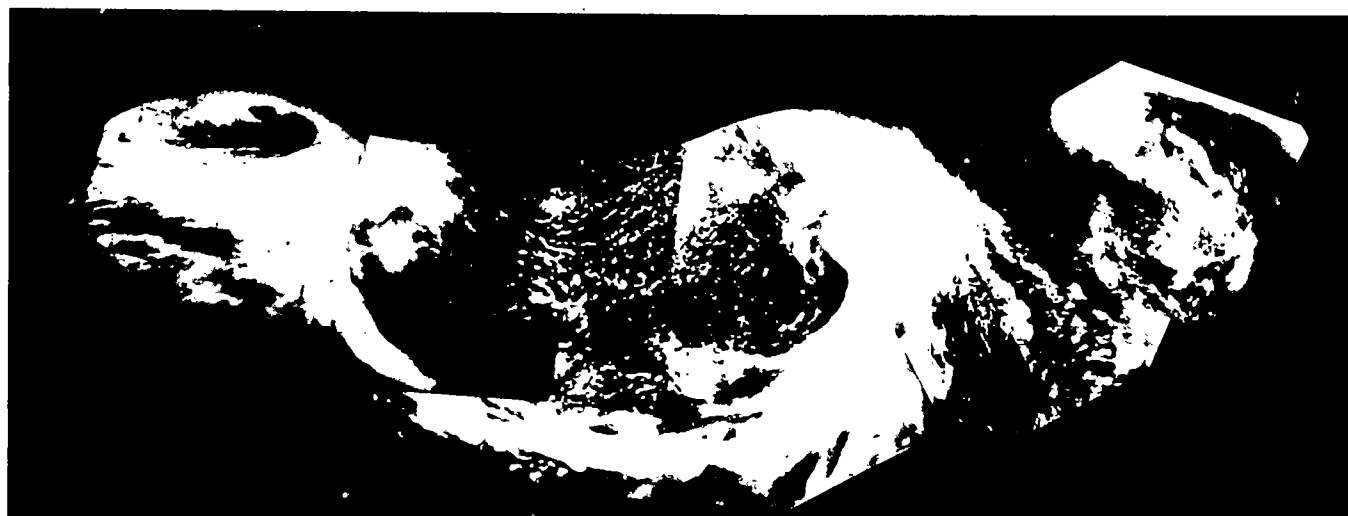


Figure 17-2. Self-weather brief.



STORM FAMILY OVER THE NORTH PACIFIC OCEAN
SATELLITE CLOUD PICTURE SUPERIMPOSED ON CONVENTIONAL WEATHER MAP



ACTUAL SATELLITE PHOTOGRAPHS

aanv179

Figure 17-3. Weather map and actual weather conditions as photographed by TIROS I observation satellite.

Note. A high cloud, icing/CAT forecast chart is prepared by the USAF Global Weather Central for high altitude operations.

d. Winds Aloft.

(1) *Winds aloft charts.* These charts are prepared twice daily and plotted on two panels of four charts. The lower level chart provides wind data in a map-like presentation using wind arrows for the second standard level above the surface at 5,000, 8,000, and 10,000 feet. The high level chart includes winds at 14,000, 25,000, 30,000, and 35,000 feet.

(2) *Upper wind prognostic charts.* These charts provide (chap 16) 12-hour forecasts of winds in the same style as winds aloft charts. These charts are used in most cases for planning purposes, based on the recency of the winds aloft charts.

e. Constant Pressure Charts. These charts (chap 14) are normally used only by the forecaster, but can provide information for a given pressure level as to winds, temperature, intensity of pressure systems aloft, and existence of clouds. Since the data for these charts represent the conditions at a standard level of pressure, they provide a three-dimensional look at the weather situation when used with other charts and information.

f. Radar Summary Chart. The radar summary chart (chap 15) presents a graphic display of areas where precipitation and the associated hazards of turbulence and icing have been occurring. This chart supplements other weather information based on observed conditions since it is taken from surface weather radar observations with wide areas of coverage. In addition, to give more complete information, general storm movement and intensity information plus any severe weather warnings are shown. The frequency of transmission for these charts varies but will average approximately 16 per day. The aviator

should refer to current sequence reports and PIREP to update as necessary.

g. Teletype Information for Planning. The teletype information normally available to the aviator is used in conjunction with facsimile maps to present the total weather picture. Because the teletype can deliver information without delay, it is used to update the various charts and maps.

(1) *Hourly sequence reports.* These reports of observed weather conditions serve as the best source for current weather conditions and NOTAM. The record reports are further updated by special reports when significant changes occur within the hour.

(2) *PIREP.* Pilot reports provide additional information to supplement the coverage of observing stations and to provide data at an altitude which could not be obtained otherwise. Civil PIREP are part of the hourly sequence reports while military PIREP are transmitted in the scan between the hourly reports.

(3) *Area Forecasts.* Area forecasts give a total picture of anticipated weather for a relatively large area. These forecasts are extremely helpful in flight planning since they include a synopsis of the weather to reinforce the aviator's overall visualization of conditions he may expect in flight. The area forecasts are issued for 18-hour periods with a 12-hour categorical outlook.

(4) *Terminal forecasts.* Terminal forecasts provide the expected weather for a specific airport and normally cover 24-hour periods. The last 6 hours of the 24-hour period are given categorically as LIFR, IFR, MVFR and VFR. The number of forecasts per day varies with the issuing agency but normally are issued every 6 hours.

(5) *Other teletype reports.* Radar reports, NOTAM summaries, winds aloft reports, forecasts, SIGMET, and AIRMET all contribute information to help the aviator assemble his total weather picture.

Section II. IN-FLIGHT PLANNING

17-6. Monitoring the Weather

There are seldom enough observations to fully describe the weather for all portions of the route. The science of forecasting does not provide for total accuracy in its prediction. The aviator must continue to analyze the weather en route and update his weather forecast using any means available. The present system provides many ways to keep abreast of current conditions, significant changes, and updated forecast conditions.

a. Weather Broadcasts. Selected FAA Flight Service Stations continuously broadcast transcribed

weather data over the voice feature of the low frequency navigational aids and VOR facilities. (See TWEB in para 11-1 through 11-5.) Additionally, all FAA Flight Service Stations having voice facilities on VOR and NDB transmit scheduled weather reports at 15 minutes past each hour. These broadcasts give the weather data for stations within a 150-mile radius of the broadcasting station.

b. Weather Advisories. Special weather developments and NOTAM are broadcast upon receipt by flight service stations. Two special weather advisories, SIGMET and AIRMET, provide immediate weather information that may endanger aircraft in flight.

BOS WS 301100
 301100-301500
 SIGMET ALFA 3. FLT PRCTN. NEW ENG ADJT CSTL WTRS NY NRN AND
 WRN PA ADJT GRTLKS MDT TURBC BLO 80 AND OVR RUF TRRN LCLY SVR BLO
 30 AGL. WNDS NR OR OVR 30 KT BLO 20 AGL. COND CONTG BYD 15Z.

Figure 17-4. Typical SIGMET.

BOS WA 300900
 300900-301600
 AIRMET BRAVO 2. FLT PRCTNS. W AND CNTRL PA INTR NY ADJT GRTLKS
 NEW ENG ADJT CSTL WTRS FOR OCNL MDT ICGIC UP TO 100 CONTG BYD 16Z.

Figure 17-5. Typical AIRMET.

(1) *SIGMET* (fig 17-4). This advisory is issued when the weather phenomena is potentially hazardous to single engine and light aircraft and in some cases to all aircraft. This would include the following:

- Tornadoes.
- Severe lines of thunderstorms (squall lines).
- Embedded thunderstorms.
- Hail three-fourths of an inch or greater.
- Severe turbulence.
- Severe icing.
- Widespread duststorms/sandstorms, lowering visibility to less than 2 miles.

(2) *AIRMET* (fig 17-5). This advisory is issued when the weather phenomena is potentially hazardous to single engine and light aircraft and in some cases to all aircraft. This would include the following:

- Moderate icing.
- Moderate turbulence.
- Sustained winds of 40 knots or more, at or within, 2,000 feet of the surface.
- Extensive areas where visibility is less than 2 miles and/or ceilings are less than 1,000 feet, including mountain ridges and passes.

(3) *Identification of SIGMET and AIRMET*. SIGMET and AIRMET are issued by the WSFO for their area and are classified by letter and number for identification. The letter identifies the area and the number is used to update. The first SIGMET issued after 0000Z would be ALFA 1 with any revisions labeled as ALFA 2, etc. If a different area of the WSFO region is concerned, it would be listed as BRAVO 1, etc. FAA Flight Service Stations broadcast SIGMET and AIRMET during their valid period as follows:

- SIGMET are transmitted at 15-minute intervals during the first hour at H + 00, H + 15, H + 30 and H + 45.
- AIRMET are transmitted at 30-minute intervals during the first hour at H + 15 and H + 45. After the first hour, an alert notice is forecast at 15 and 45 minutes past each hour advising pilots which

SIGMET or AIRMET are valid. The aviator receiving these notices should contact the nearest flight service station for information on these advisories to determine if their flight may be affected.

c. Pilot to Weather Briefer/Forecaster.

(1) *FAA Flight Service Station*. Direct pilot weather briefing service is available by radio contact to any FAA Flight Service Station. This would provide the aviator with available in-flight weather data much like that offered during a preflight briefing.

(2) *Pilot-to-Metro Service*. Pilot-to-Metro Service can provide an update to weather forecasts for the in-flight phase. The advantage of this service over that provided by FAA Flight Service is that a forecaster is available rather than a briefer. Locations of Pilot-to-Metro facilities may be found in the FLIP En Route Supplement.

d. En route Flight Advisory Service (EFAS). This is a civil advisory service which parallels the military Pilot-to-Metro Service described above. This service is designed to provide timely weather information pertinent to the type of flight, route, and altitude along prominent airways. It is provided by selected FAA Flight Service Stations using the station name followed by the phrase FLIGHT WATCH.

Note. En route Flight Watch is not intended to be used for flight plan filing, routine position reporting, or to obtain a complete briefing in lieu of contacting an FSS or NWS office prior to the flight.

17-7. Weather Radar

Many times a mission requires a flight under conditions of hazardous weather in the form of heavy precipitation areas, thunderstorms, and possible tornadoes. In cases where visual circumnavigation is not possible, the best tool for avoidance is radar.

a. Ground Based Systems. Ground based radar facilities offer the aviator a means for identifying

potentially dangerous areas of weather with the additional capability of vectoring the aircraft to avoid them.

(1) *ATC radar.* Air traffic control radar can detect weather but is limited in capability when compared to true weather radars. Some of the shortcomings of ATC radar are—

- Frequency and wavelength are not best suited for weather detection.
- They lack antenna tilt capability.
- They do not have iso-echo (contour) capability for best weather interpretation.
- When aircraft targets are obscured by weather, they must adjust equipment to eliminate weather interference.
- ATC radar is primarily for traffic control not for weather advisories.

The use of ATC radar to advise pilots of isolated storm cells and the vectoring around them is a very good service. However, the aviator should be aware that they do not have a real weather vectoring capability in extensive storm areas or in lines of thunderstorms.

(2) *Weather radar facilities.* Many of the Pilot-to-Metro facilities have weather radar equipment (see FLIP supplement) and can provide radar storm advisory service to en route aircraft. These radar units operate at a frequency and wavelength best suited to weather detection. They also have antenna tilt and calibrated gain control circuits or contour circuitry for good interpretation of storm cell echoes. The weather personnel using this type equipment can advise pilots as to the horizontal extent and top of squall lines, individual thunderstorms, thunderstorm complexes, and other phenomena. The weather personnel can determine which cells may represent severe weather, where it appears easiest to penetrate a line of thunderstorms, whether an echo system is too high to overfly, the most open route by which a terminal can be approached, and other needed information. All of this is usually available through a simple radio call to weather personnel through the PMSV frequency.

Note. When using PMSV/WX radar for vectors around storms, the aviator must coordinate with the appropriate ATC controller for needed air traffic clearance.

b. Airborne Weather Radar. The use of airborne weather radar is the best possible means of avoiding severe weather areas in flight. The advantages of this system are that the immediate areas in front of the aircraft can be scanned by the crew while in flight, thus providing more timely information, and the range of the equipment is normally appropriate to the airspeed of the aircraft. A better portrayal of

conditions is possible by scanning the area at flight altitude than by ground based equipment using antenna tilt. For additional information on airborne weather radar usage see chapter 15.

17-8. Pilot Reports (PIREP)

Pilot reports provide the forecaster with timely and accurate observations of conditions aloft which cannot be observed from the ground. Such conditions observed between weather reporting stations are often the first indication of the beginning of hazardous flying weather, especially turbulence and icing conditions.

a. Requirement to Report. Both AR 95-1 and FAR 91 require that in-flight and post flight weather reports be made to requesting agencies. FAA stations are required to solicit and collect PIREP describing conditions aloft whenever ceilings are at or below 5,000 feet, visibilities are at or below 5 miles, or thunderstorms are reported or forecast. The pilot should realize the importance of his contribution to the system when volunteering reports of cloud tops, upper cloud layers, thunderstorms, ice, turbulence, strong winds, and other significant information.

b. Making the Report. The main criteria for reporting is when unforecast or hazardous weather conditions are encountered which have not been forecast. PIREP should be given to the FAA ground facility with which the aviator is communicating, i.e., Air Route Traffic Control, Approach Control, or FSS. In addition to complete PIREP, pilots can materially help round out the inflight weather picture by adding to routine position reports, both VFR and IFR, the type aircraft and the following phrases as appropriate:

ON TOP
BELOW OVERCAST
WEATHER CLEAR
MODERATE (or HEAVY) ICING
LIGHT, MODERATE, SEVERE, OR EXTREME
TURBULENCE
FREEZING RAIN (or DRIZZLE)
THUNDERSTORMS (location)
BETWEEN LAYERS
ON INSTRUMENTS
ON AND OFF INSTRUMENTS

If pilots are unable to make PIREP by radio, they may be made to the FSS or WSO upon landing.

c. Body of the Report. The actual report should consist of the following:

- (1) Location.
- (2) Time (GMT).
- (3) Phenomena reported.

(a) Any hazardous weather (with explanatory remarks such as direction of movement of storms, frequency of lightning, and/or hail).

(b) Bases and/or tops of cloud layers and coverage if known.

(c) Smoke, haze, or dust layer with top of layer and the horizontal visibility in the layer.

(d) Marked wind changes.

(e) All turbulence with intensity, duration, and proximity to clouds.

(f) All airframe icing with intensity and type.

(4) Altitude of phenomena.

(5) Type of aircraft.

Airframe icing and turbulence should be evaluated according to criteria listed in current navigation publications (FLIP Supplements). The following terms should be used to indicate the duration of the reported phenomena.

Reporting Term	Definition
Occasional	less than one-third of the time

Intermittent -----one-third to two-thirds of the time

Continuous -----more than two-thirds of the time.

d. *Uses of PIREP.* The various uses of pilot reports are as follows:

(1) Control towers use the reports to expedite the flow of traffic and forward reports to other interested offices.

(2) The flight service station uses the reports to brief other pilots.

(3) Weather Services Offices use them for briefing and to aid in forecasting.

(4) Air Route Traffic Control Centers use it to help flow their traffic with regard to both route and altitude.

(5) Weather Service Forecast Offices use the data for issuing advisories of hazardous weather conditions, pilot briefings, and forecasting.



APPENDIX A

REFERENCES

A-1. Army Regulations (AR)

95-series	(Aviation Regulations.)
310-25	Dictionary of United States Army Terms.
310-50	Authorized Abbreviations and Brevity Codes.

A-2. Department of the Army Pamphlets (DA Pam)

108-1	Index of Army Motion Pictures and Related Audio-Visual Aids.
310-series	(Military Publications Indexes.)

A-3. Field Manuals (FM)

1-5	Instrument Flying and Navigation for Army Aviators.
1-50	Fixed Wing Flight.
1-51	Rotary Wing Flight.

A-4. Miscellaneous

Airman's Information Manual (Parts I and II).	
Aviation Weather	For Pilots and Flight Operations Personnel (available from Superintendent of Documents, US Government Printing Office, Washington, D.C. 20402).
AFM 51-12	Weather for Aircrews (available from USAF Publications Distribution Center, Baltimore, Maryland 21220)
FAR 91	General Operating and Flight Rules (available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)
7110.100	Flight Services Handbook (available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)
FMH 1	Federal Meteorological Handbook 1 (available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)



APPENDIX B

UNITS OF MEASUREMENT FOR METEOROLOGICAL ELEMENTS

Table B-1. Conversion From Inches of Mercury to Millibars

In Hg	0	1	.2	3	4	.5	6	.7	8	.9
28	948	952	955	958	962	965	968	972	975	979
29	982	985	989	992	996	999	1,002	1,006	1,009	1,013
30	1,016	1,019	1,023	1,026	1,030	1,033	1,036	1,040	1,043	1,046
31	1,050	1,053	1,057	1,060	1,063	1,067	1,070	1,074	1,077	1,080

Table B-2. Dew Point and Moisture Content at 1,000-Millibar Pressure

Dew Point °F.	Water vapor in g/kg (approximate)	Dew Point °F.	Water vapor in g/kg (approximate)
90 -----	31	40 -----	5.4
80 -----	22	30 -----	3.6
70 -----	16	20 -----	2.3
60 -----	11	10 -----	1.5
50 -----	7.7		

Explanation. Any parcel of air with a dew point temperature of 70° F contains approximately 16 grams of water vapor per 1,000 grams of air (atmosphere pressure at 1,000 millibars); or, any parcel of air containing 11 grams of water vapor per 1,000 grams of air would have a dew point of approximately 60° F., etc.

Table B-3. The Standard Atmosphere

	Metric units	Dynamic units	English units
Sea level temperature -----	15° C. ----- 288.15° K.		59° F.
Sea level atmospheric pressure -----	760 mm of mercury or 10,332.276 kg/m ² .	1,013,250 dynes/cm ² 1,013.25 mb.	29.92 in. of mercury 14.696 lb/in. ²
Sea level atmospheric density -----	1.2250 kg/m ³ .		
Standard vertical temperature gradient (lapse rate) -----	0.0065° C/m ----- 2° C/1,000 ft -----		0.003566° F/ft 3.6° F/1,000 ft
Standard isothermal temperature -----	-56.5° C. (tropopause) -----		-69.7° F.
Temperature of the ice point -----	273.15° K.		
Sea level mean molecular weight -----	28.9644 × 10 ⁻³ kg/mole.		

Table B-4. Miscellaneous Constants and Units

Density of water at 15° C. ¹ -----	0.9991286 g/ml
Latent heat of fusion of ice -----	79.7 g-cal/g
Latent heat of vaporization of water -----	594.9 g-cal/g at 0° C.
	539.1 g-cal/g at 100° C.
1 meter -----	39.37 in
1 kilogram -----	2.2046 lb
1 statute mile -----	5,280 ft
1 nautical mile -----	6,080 ft (1.15 statute miles)
1 kilometer ² -----	3,281 ft
1 inch -----	2.54 cm
1 inch Hg -----	33.86395 millibars
1 millibar ² -----	0.0295299 in Hg
1 m/sec -----	2.2369 mph
1 m/sec -----	1.943 knots
1 mph -----	0.8684 knots
1 nautical mile -----	1.15 statute miles
Solar constant -----	1.932 cal/cm ² /min at the mean solar distance
Angular velocity of earth's rotation () -----	7.29 × 10 ⁻⁵ radian/sec

¹ For temperature conversion between F. and C. scales, use the scale on figure 5-8 (Skew T, log p Diagram).² For pressure-altitude relationship in the standard atmosphere, use ICAO sounding on figure 5-8 (Skew T, log p Diagram)

Table B-5. Wind Direction—Degrees to Compass Points

Degrees	Compass point
349-011 -----	N
012-033 -----	NNE
034-056 -----	NE
057-078 -----	ENE
079-101 -----	E
102-123 -----	ESE
124-146 -----	SE
147-168 -----	SSE
169-191 -----	S
192-213 -----	SSW
214-236 -----	SW
237-258 -----	WSW
259-281 -----	W
282-303 -----	WNW
304-326 -----	NW
327-348 -----	NNW

Table B-6. Surface Wind Character

Wind speed in knots	Character in wind
0 -----	Calm
1-3 -----	Light air
4-6 -----	Light breeze
7-10 -----	Gentle breeze
11-16 -----	Moderate breeze
17-21 -----	Fresh breeze
22-27 -----	Strong breeze
28-33 -----	Moderate gale
34-40 -----	Fresh gale
41-47 -----	Strong gale
48-55 -----	Whole gale
56-63 -----	Storm
64+ -----	Hurricane

Table B-7. Approximate Force of the Wind Against a Stationary Object at Sea Level in Standard Atmosphere

Wind speed (knots)	Force (pounds per square foot)
10 -----	.34
20 -----	1.36
30 -----	3.05
40 -----	5.43
50 -----	8.48
60 -----	12.21
70 -----	16.62
80 -----	21.71
90 -----	27.48
100 -----	33.92

Table B-8. Approximate Density Altitude Computations to the Nearest 100 Feet

Pressure Altitude (feet)	Air Temperature										
	°F 97	90	82	75	68	61	54	47	39	32	25
	°C 36	32	28	24	20	16	12	8	4	0	-4
Sea level -----	2,500	2,100	1,600	1,100	600	100	-400	-900	-1,400	-1,900	-2,300
500 -----	3,100	2,700	2,200	1,800	1,300	800	300	-200	-700	-1,200	-1,600
1,000 -----	3,700	3,200	2,800	2,400	1,900	1,400	900	500	-100	-600	-1,100
1,500 -----	4,300	3,900	3,400	3,000	2,500	2,000	1,500	1,100	600	100	-500
2,000 -----	4,900	4,500	4,000	3,600	3,100	2,600	2,200	1,700	1,200	700	200
2,500 -----	5,500	5,100	4,600	4,200	3,700	3,200	2,800	2,300	1,800	1,300	800
3,000 -----	6,300	5,700	5,200	4,800	4,300	3,800	3,400	2,900	2,500	2,000	1,500
3,500 -----	6,800	6,300	5,900	5,400	4,900	4,400	4,000	3,500	3,100	2,600	2,100
4,000 -----	7,500	7,000	6,600	5,900	5,500	5,000	4,600	4,100	3,700	3,200	2,700
4,500 -----	8,000	7,500	7,100	6,500	6,000	5,500	5,100	4,600	4,200	3,600	3,200
5,000 -----	8,500	8,000	7,600	7,100	6,500	6,100	5,600	5,200	4,700	4,200	3,700
5,500 -----	9,100	8,600	8,200	7,700	7,100	6,700	6,200	5,800	5,300	4,700	4,300
6,000 -----	9,700	9,200	8,800	8,300	7,800	7,300	6,900	6,400	5,900	5,300	4,900
6,500 -----	10,300	9,800	9,400	8,800	8,400	7,800	7,400	7,000	6,400	6,000	5,600
7,000 -----	10,800	10,400	10,000	9,500	9,000	8,500	8,100	7,600	7,100	6,700	6,200
7,500 -----	11,400	11,000	10,600	10,200	9,700	9,200	8,700	8,300	7,800	7,300	6,800
8,000 -----	12,100	11,600	11,200	10,800	10,300	9,800	9,200	8,800	8,400	7,900	7,500



APPENDIX C

WEATHER OUTSIDE THE TEMPERATE ZONE

Section I. POLAR AND SUBPOLAR REGIONS

C-1. General

a. Flights in polar and subpolar regions present special problems for the aviator. Most of the weather phenomena of special significance in these regions occur at low altitudes or at the surface. Terminal weather conditions are serious hazards in polar flight operations. Obstructions to visibility and depth perception make landings and takeoffs difficult. Iced runway conditions require special flight techniques during takeoff.

b. Although extremely cold air is typical of the polar and subpolar regions, the characteristic flight problems of cold air are not limited to these geographical areas. Flight hazards discussed in this appendix are applicable to areas of cold temperature wherever found.

C-2. Climatic Boundaries

a. Polar Region. The polar region is that part of the earth where the mean annual temperature is 32° F. or less and where the mean temperature for the warmest month is less than 50° F. In North America this region includes the northern coast of Alaska and Canada, the Canadian Arctic Archipelago, most of Labrador, Greenland, the Svalbard Archipelago, and the southern end of the Aleutian Island chain. The southern boundary of the polar region roughly follows the 60th parallel.

b. Subpolar Region. The subpolar region is more difficult to delineate than the polar region. In North America it includes the area between the southern limit of the polar region and the 40° F. isotherm of average annual temperature. Across the United States the boundary roughly follows the 48th parallel, but it then swings northward to include part of Alaska and the Aleutian Island chain.

C-3. Weather

a. Weather phenomena in the polar region are confined to a relatively shallow atmospheric layer near the surface because of the lack of convective activity to carry the moisture to higher levels. High-altitude flight is comparatively weather-free, but poor air-to-ground visibility, coupled with the mountains' refractive effect on radio waves, may complicate navigation at high altitudes.

b. The proportion of clear days to overcast days at Alaskan stations, for example, is often less than 1:3 (fig C-1). In the course of a year, only those stations in interior Alaska average more clear days than cloudy days. The best flying conditions in the Aleutians, along the southeast Alaskan coast, and over the Seward Peninsula occur during the winter. The Alaskan gulf coast and interior regions present optimum flying conditions during the summer. The poorest (annual) flying conditions of Alaska exist in the Aleutians and the coastal section of the mainland. Although in the interior and Anchorage area ceilings and visibilities are below 2,000 feet and 6 miles for more than 10 percent of the time, these conditions exist more than 50 percent of the time in the Aleutians and along the southwest coast bordering the Alaskan gulf.

C-4. Terminal Hazards

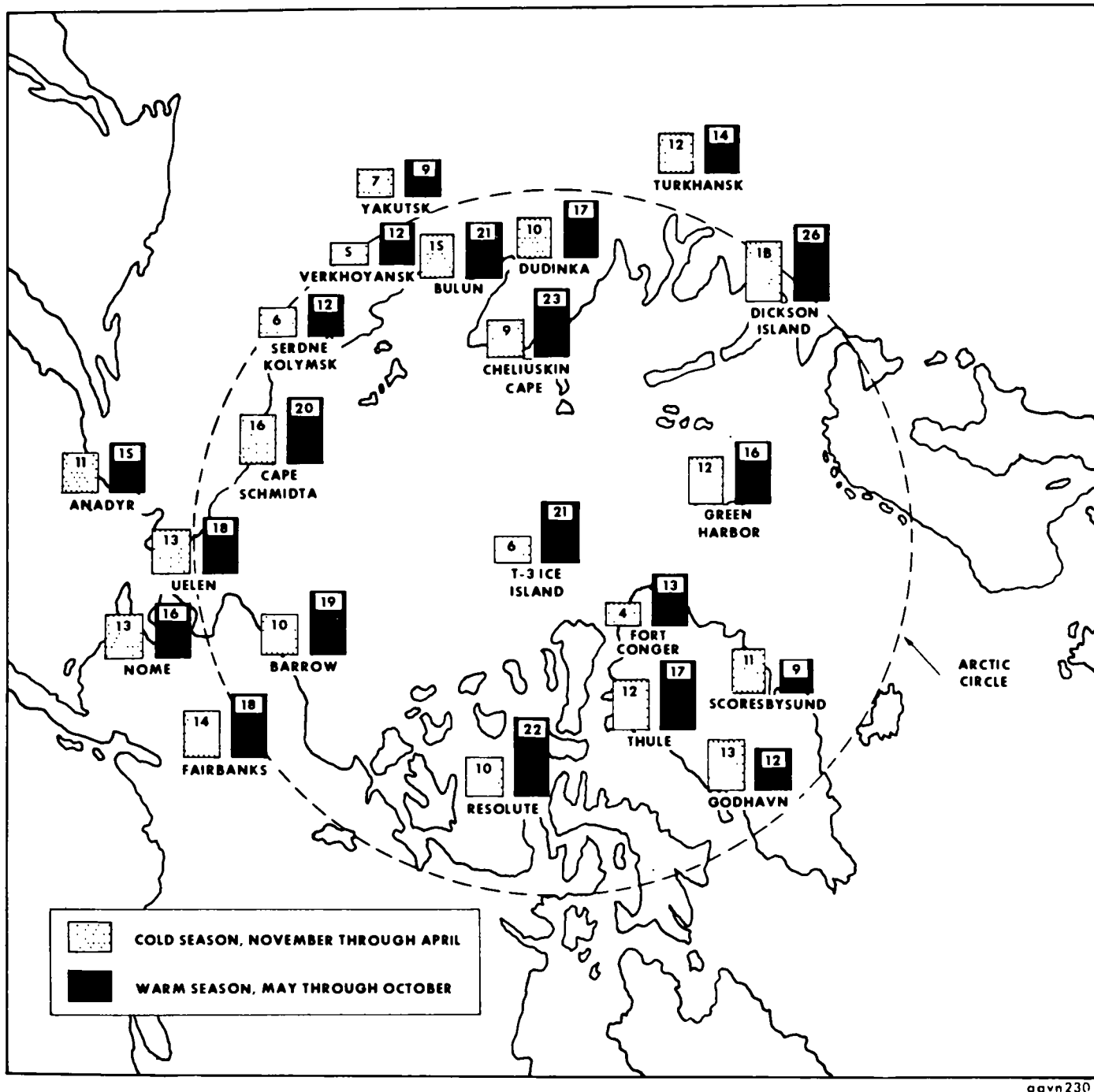
a. Depth Perception. The effect of polar sunlight and weather phenomena on depth perception is the worst flight hazard encountered. Over newly formed snow on a dull overcast day, shadows are not visible; the effect is similar to that of glassy water, so that depth perception is extremely difficult after takeoff. This atmospheric condition is called a *whiteout*.

b. Fog.

(1) Advection fog and low stratus clouds generally prevail in coastal polar regions (fig C-2). They are caused by a combination of orographic lifting of moist air and contact of the relatively warm air from the sea with the cold land surface. Usually they are found on the windward side of islands, since adiabatic heating or turbulence normally reduces the formation of fog on the lee sides of mountains and islands. The fog and stratus quickly diminish inland because of the extreme coldness of the snow-covered land mass.

(2) Steam fogs occur when the cold, dry air passes from the land areas over the relatively warm ocean. The rate of evaporation from the warm water surface is high, but the cold air cannot support moisture in the vapor state. Condensation takes place just above the water surface and is visible as "steam" rising from the ocean.

(3) Polar ice fog in the interior land regions occurs most frequently when the ground temperature



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Figure C-1. Average number of overcast days per month.

is near or below -20°C . Ice fog results from sublimation of water vapor in the atmosphere during periods of relatively clear weather. The small crystals of ice fog remain suspended in the atmosphere for long periods of time. Ice fog produces neither rime nor glaze on exposed surfaces contacted; however, it may produce scintillating effects in sunlight or other light beams, halos, luminous vertical columns over lights, and light diffusion. Over snow-covered surfaces, ice fog is invisible from the air.

(4) Ice crystals, as a form of precipitation, produce the same effects on vision as ice fog. The rate of fall with ice crystal precipitation is very gradual and almost negligible. Ice crystals may fall from either cloudy or cloudless skies.

c. Drifting and Blowing Snow. Winds of 12 knots lift the surface snow a few feet off the ground, hiding objects such as rocks and runway markers. This drifting snow does not restrict surface visibility above 6 feet. Winds of 15 knots pick up dry, powdery



Figure C-2. Fog and stratus clouds over polar coastal areas.

snow and lift it high enough to obscure buildings when the surface is irregular (fig C-3). The strong fall winds and the winds in arctic blizzards may lift this *blowing* snow to heights above 1,000 feet and produce surface drifts over 300 feet deep. Although surface drifting of snow may occur without restricting vertical visibility, the drifts can still obstruct horizontal visibility during takeoff and landing. All objects protruding into the wind stream during drifting or blowing snow create drifts to their lee side.

C-5. Flight Problems in Polar Regions

a. Takeoff.

(1) *Engine temperatures.* The operator's manual for each aircraft specifies cold-weather flight procedures and explains the proper use of special cold-

weather equipment. Reciprocating engines may require preheating before starting. Surface temperatures in polar areas are frequently 15° F. to 30° F. colder than the temperatures at flight level.

(2) *Windshield icing.* Even when precautions are taken prior to flight to prevent structural ice accumulation during takeoff, windshipped ice or frost may still form if ground haze is present. Thus, when haze is present, the aviator should be prepared to go on instruments at any time during takeoff.

(3) *Carburetor icing.* Carburetor icing is likely along coastal regions and around islands when the moisture content of the air is high and the temperature is warm as the air moves onshore. If the air is cold and dry, there is no danger of carburetor icing; however, under extreme low-temperature conditions



Figure C-3. Blowing snow.

in interior polar areas, the application of carburetor heat will aid fuel vaporization and improve engine operation.

b. Inflight.

(1) *Structural ice.* After takeoff from a snow-covered field, the landing gear, flaps, and other movable structural parts of the aircraft should be cycled to loosen ice or packed snow and to prevent parts from freezing in an "up" position.

(2) *Moist air indicators.* The aviator should remain alert to the visible signs of high atmospheric moisture content. In cold air with low moisture content, snowflakes form as hard, dry, small grains. In moist, warmer air, the snow may appear as large flakes or pellets. In regions of supercooled water droplets, the greater the moisture content the more rapidly ice gathers on exterior parts of the aircraft.

(3) *Radio contact.* In areas of precipitation and ice crystal formation, static electricity may seriously interfere with radio transmission and reception. A change of altitude or airspeed may help to correct the problem of radio contact. The effects of mountainous terrain, snow-covered surfaces, and dense air layers also result in a bending of the radio waves, which further complicates radio communication and radio navigation under instrument conditions.

(4) *Altimeter error.* In polar regions, strong winds over rough terrain and colder than standard

air cause serious altimeter errors. The aviator should allow for an ample safety margin in selecting flight altitudes over mountainous terrain.

c. Landing.

(1) *Mechanical turbulence.* Katabatic (fall) winds are common in polar regions and may blow continuously for days. As these cold winds drain from high plateau or mountain areas down to lower elevations, their speed increases abruptly and may exceed 100 knots. Arctic fronts and blizzards also cause frequent, strong winds. As the wind moves near the surface over obstructions such as ridges, cliffs, bluffs, buildings, and jagged ice or stone peaks, strong gusts develop in eddies and may move with the wind across the airfield. For positive control of the aircraft, the aviator should land as far from the lee sides of these obstructions as possible.

(2) *Runway icing.* Aircraft exhaust may freeze and settle onto the runway. The frozen exhaust moisture also may remain suspended in the air as ice crystals or ice fog and limit visibility over the runway.

C-6. Arctic and Polar Air Masses

a. The classification of arctic and polar air masses is based on the geographical region in which they form. Arctic air masses originate over the Arctic ice cap or in the great polar high over the Greenland ice cap. These air masses generally form north of the

Arctic Circle ($66\frac{1}{2}^{\circ}$ north latitude). The source regions of polar air masses are generally between 40° and $66\frac{1}{2}^{\circ}$ north latitudes. As cold air accumulates in these source regions, the increasing density causes it to drain southward—to move out of its source region. Arctic and polar air masses may move as far south as Cuba and Mexico during the winter months. As these air masses move, they bring in clear skies, stable air, and low temperatures.

b. Frontal activity is common between the arctic and polar air masses. The cyclones and their asso-

ciated fronts cause some strong wind conditions, but the clouds and precipitation forming in the cool, dry polar air are not extensive. Arctic cold fronts frequently increase the temperature at the surface for a short time after passage. The mechanical turbulence produced by the strong frontal winds may upset the surface inversion layer, with the warmer air from aloft descending to the surface. The invasion of arctic air masses into midwestern United States brings in the coldest weather of the winter over large areas of the country.

Section II. TROPICAL WEATHER

C-7. General

a. The Tropics include the vast region lying between the Tropic of Cancer and the Tropic of Capricorn ($23\frac{1}{2}^{\circ}$ north latitude and $23\frac{1}{2}^{\circ}$ south latitude respectively). Tropical weather may also occur more than 45° from the Equator, especially on the east coast of continents.

b. The predominant pressure field in the Tropics is low and the pressure gradient is weak. The presence of low pressure throughout the year is a result of the following two pressure systems:

(1) *The equatorial trough.* This trough contains the intertropical convergence zone—a zone which migrates north and south of the Equator, and is present all year.

(2) *The thermal lows.* These lows are formed by the intense heating of the continents by perpendicular or near-perpendicular solar radiation during all seasons.

c. Most weather in the Tropics is *air mass* and can be classified as *oceanic tropical weather* and *continental tropical weather*. Along coastal regions and over islands, a transitional effect takes place between ocean and land.

C-8. Oceanic (Maritime) Tropical Weather

Weather over open seas in the Tropics is characterized by cumuliform clouds. About one-half of the sky is covered with cumulus clouds with bases averaging 2,000 feet and tops averaging 8,000 feet. Frequently these clouds produce scattered rain showers, but visibility is good outside of the shower areas. The surface air and upper air temperatures are quite uniform over the open ocean. The temperature variation of the air seldom exceeds 2° C. daily or annually. The freezing level is approximately 16,500 feet throughout the year. Surface pressure patterns change very little (except in tropical storms) and the pressure gradient is weak.

C-9. Island and Coastal Tropical Weather

a. Daily pressure and temperature variations are fairly constant along coastal areas and over islands. The daily land and sea breezes control the air movement. During the day, moist ocean air moves on-shore and is lifted and heated by the land surface. The lifting produces an increase in the number and intensity of cumuliform clouds and in the amount of precipitation. Towering cumulus clouds are often the aviator's first indication that he is approaching an island (under the blanket of small ocean cumulus) below the aircraft.

b. Where high mountains parallel the continental shorelines or where the continental area forms a high plateau, the moisture from the maritime air is condensed by orographic lifting and adiabatic cooling. The windward slopes may receive rainfall exceeding 400 inches a year at some stations where the prevailing surface airflow is from a semipermanent high pressure cell over the sea toward a thermal low over the continent (e.g., Cherrapunji, India).

C-10. Continental Tropical Weather

The weather over interior continental areas within the Tropics is subject to extreme climatic variation. Factors which control the climate are the pressure pattern and windflow; orientation, height, and extent of coastal mountain ranges; altitude of the continental area; and rate of evaporation from the surrounding ocean surface. Various combinations of these factors produce tropical weather ranging from the hot humid climate of the lower Congo River to the arid Libyan Desert and the snowcapped mountains of Kenya and South America. However, the two *major* climatic groups of the tropical continental areas are the arid (or semiarid) climates and the humid (jungle or rain forest) climates.

a. *Arid Tropical Weather.* The climate for land areas to the lee of mountain ranges or on high pla-

teaus is characterized by hot, dry, unstable continental air (e.g., the desert regions of South America and Africa). The afternoon temperature may be in excess of 100° F. in these areas, but the night temperature may drop below freezing. Strong convection is present during the day, but the relative humidity is so low at the surface that the cumuliform cloud bases are above 10,000 feet. Precipitation falling from high-based thunderstorm clouds often evaporates completely before reaching the surface. The "dry" thunderstorms, however, produce squall winds and may cause severe dust or sandstorms. These storms are a hazard to aircraft because of the severe turbulence aloft and the restricted ceiling and visibility, accompanied by gusts and squalls, at the surface. The blowing sand may cause extensive damage to inadequately protected aircraft on the ground.

b. Humid Tropical Weather. Where no mountains or high terrain are present to obstruct the flow of maritime air onshore, the warm moist oceanic air influences wide continental areas of the Tropics. Cloudiness and precipitation are at a maximum over these regions of jungle and tropical rain forests.

(1) In humid tropical climates, the daily variation of wind direction and speed determines the daily variation in cloudiness, temperature, and precipitation. Slight shifts in the wind direction may cause the air to lose its moisture over hills or to come from a different marine source region with less moisture. Slight increases in wind speed may reduce local contact heating and result in fewer convective currents and clouds.

(2) Clouds are predominantly cumuliform with afternoon cumulonimbus, but thick early-morning steam fog often forms in the jungles. The average daytime cloud coverage is approximately 60 percent of the sky throughout the year, with maximum cloud coverage during the day and minimum near sunset. The high moisture content and extensive cloud coverage reduce summer heating and winter cooling.

(3) The annual range in temperature for jungle stations may be less than 2° F., but the daily range is often 30° F. or more. When afternoon showers occur, the descending cold air currents may produce nights with temperatures in the 60° F. range. These rain showers are very heavy and produce low clouds that may reduce ceiling and visibility to near zero.

C-11. Other Tropical Phenomena

The principal types of special weather phenomena observed in the Tropics are tropical cyclones, monsoons, easterly waves, the trade inversion, and the intertropical convergence zone.

a. Trade Inversion. Water surfaces cover most of the area in the Tropics. Convective mixing in the lower levels carries the moisture from the warm

ocean surface up to approximately 8,000 feet. The actual height of the moist layer varies considerably, depending on the particular local weather situation. Above the moist layer is a very dry air layer caused by subsidence in the subtropical oceanic anticyclones. The two layers are separated by a well-defined temperature inversion known as a *trade inversion* (fig C-4). The actual height of the trade inversion is a qualitative indication of whether convergence or divergence is occurring in the lower levels (moist air layers). The moist layer will be considerably higher than average if the air is converging at or near the surface. The inversion will be lower than average if the air is diverging (has sinking air currents) at the surface. Flight above the trade inversion avoids the roughness and cloudiness of the moist air layer.

b. Intertropical Convergence Zone. The subtropical high pressure areas of both hemispheres are separated in the region of the heat equator by a trough of low pressure in which hot tropical air is converging and rising. This is called the *intertropical convergence zone* (ITCZ). The ITCZ is not a true front because the discontinuity of the air density is not significant. The convergence zone has the appearance of a front; however, because the rising warm, moist air produces a line of towering cumulus clouds and thunderstorm activity, with tops of the clouds above 60,000 feet. The ITCZ moves considerably northward in the summer and somewhat southward in the winter as a result of the migration of the direct rays of solar radiation with the seasons (fig C-5).

c. Easterly Waves. Easterly waves are lines of definite wind shift and barometer depression (fig C-6) originating near the southeastern perimeter of the subtropical high pressure cells in the Northern Hemisphere. The top of the moist layer of air (trade inversion) is low (5,000 to 8,000 feet) and the sky condition is either clear or scattered, with cumulus clouds west of the wave. The moist air layer frequently extends to 15,000 feet, or more, eastward of the surface position of the wave. In this area, thunderstorms, low ceilings, rain, and hazardous weather predominate. The hazardous weather forms a line, normally oriented north-south, and resembles the cold frontal weather of the middle latitudes. Easterly waves travel around the southern periphery of the subtropical highs from east to west, with the prevailing easterly circulation typical of the Tropics in the Northern Hemisphere. These atmospheric waves are common in all seasons of the year but are strongest in the summer and early fall. Occasionally the effects of easterly waves are felt along the Gulf coast section of the United States. Waves which are originally weak and hardly discernible on the weather map may deepen rapidly in 24 hours and become the spawning ground of tropical cyclones and hurricanes.



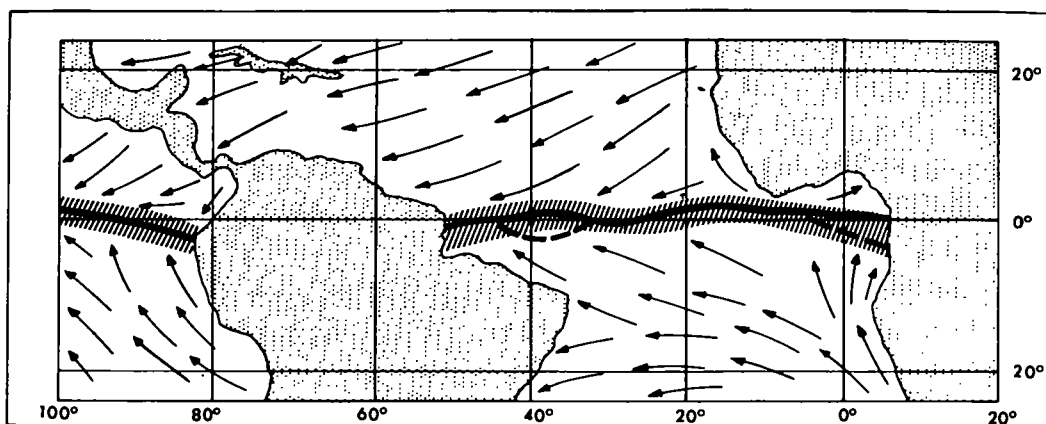
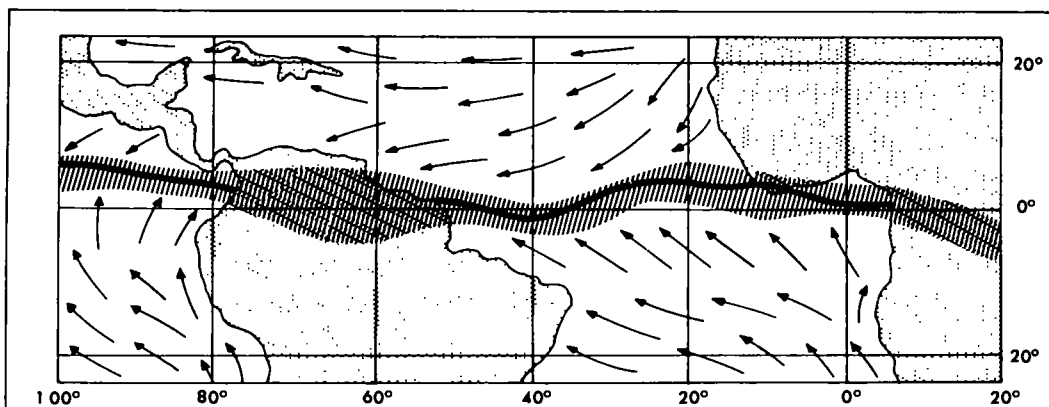
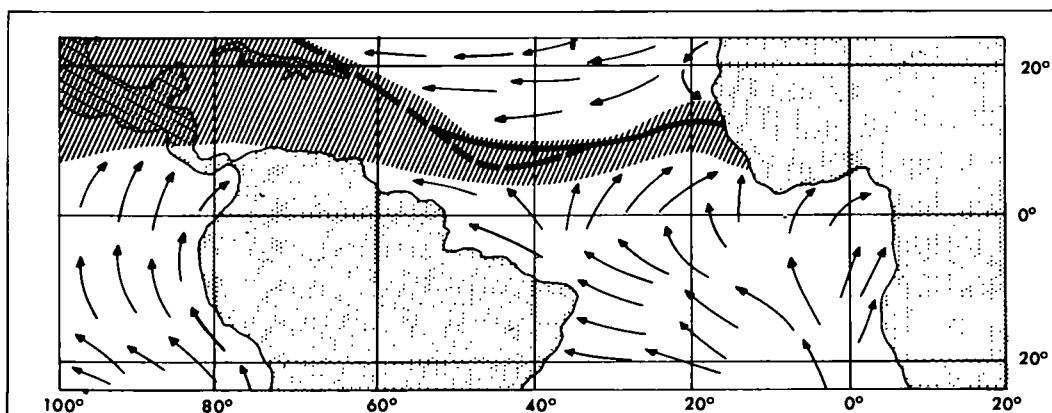
Figure C-4. Variation in height of trade inversion.

d. *Other Hazardous Weather Zones.* There are several less frequent atmospheric discontinuities which develop in the tropical airstreams. These often appear in synoptic charts as weak *polar troughs* extending from middle latitude frontal systems. The weather along a polar trough (fig C-7) is similar to that found along an easterly wave, but its movement is from west to east and it is accompanied by a considerable temperature reduction. The cloud system tends to weaken as the trough moves eastward, whereas the easterly wave is very likely to intensify as it moves westward. *Shear lines* (fig C-8) also form in the Tropics when the leading edge of a continental polar air mass advances southward and displaces the semipermanent oceanic high. Mixing in the southern latitudes causes the density discontinuities across the front to disappear, leaving only a wind shift across the diffuse front. Convergence and cumuliform activity may still be found along this wind shift line. As the anticyclone behind the shear line advances, the high pressure area ahead of the shear line tends to weaken and the two highs gradually merge. The narrow band of bad weather is then replaced by a freshening of the trade winds.

C-12. Flight Problems Within the Tropics

In tropical regions over the ocean, weather observation and reporting stations are few and far between. The aviator must often use his knowledge of the normal height of the moist layer and cloud tops to detect his approach to a zone of bad weather.

a. *Flight in the ITCZ.* The density and vertical extent of the cumulus clouds in the ITCZ vary considerably. Most of the time a scattered row of cumulonimbus, accompanied by considerable middle and high clouds, typifies the ITCZ. These clouds occasionally become so congested it is impossible to circumnavigate them. The technique for crossing the ITCZ is determined from the performance capabilities of the aircraft. With aircraft service ceilings of 16,000 feet or more, the aviator rarely has difficulty in climbing over saddlebacks between cloud tops. Clouds whose tops are less than 14,000 feet normally do not contain serious hazards because the tops are still below the freezing level. The principal danger during low-level flight under the clouds (where the precipitation is light), or during actual cloud penetration, lies in entering the cumulonimbus clouds whose tops

FEBRUARY**MAY****AUGUST****NOVEMBER**

- MEAN POSITION OF FRONT
- ▨ DAY BY DAY MOVEMENT OF FRONT
- - - SUBSIDIARY SQUALL ZONE

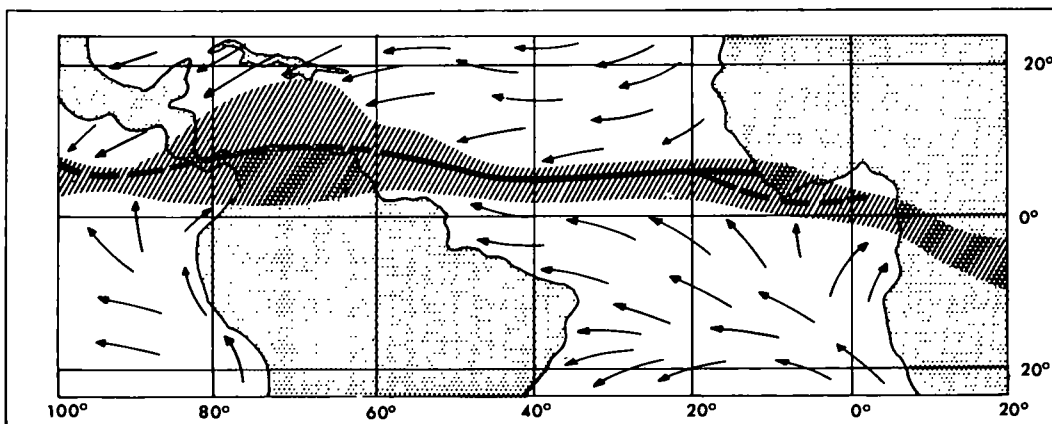


Figure C-5. Average position of intertropical convergence zone, South Atlantic area.

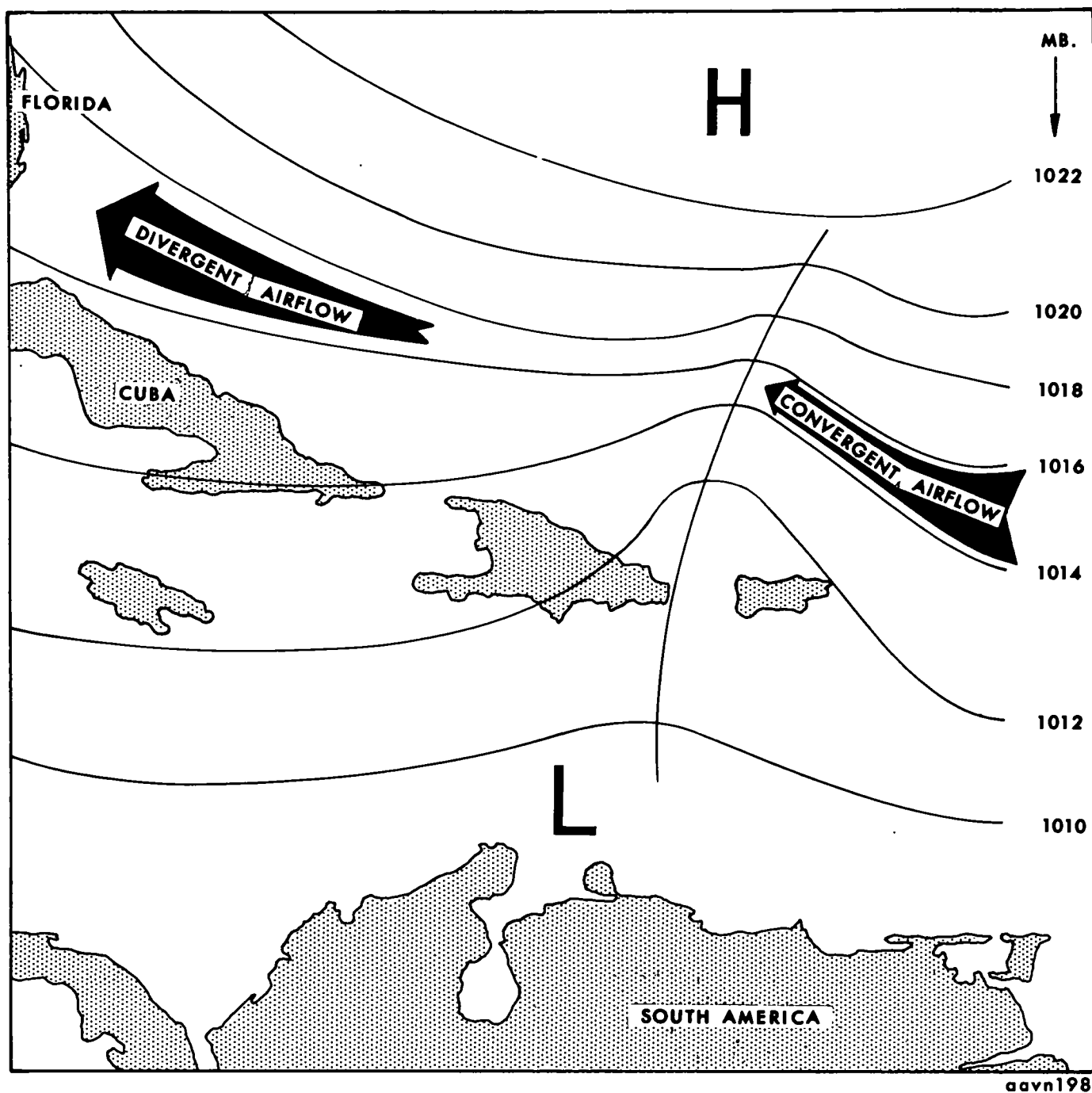


Figure C-6. An easterly wave.

extend well above the freezing level. In these thunderstorms strong turbulence, gusts, hail, lightning, and heavy precipitation are present. When approaching the ITCZ, it is dangerous to fly into clouds when the actual heights of the tops are unknown. The aviator should not attempt a low-level flight under thunderstorms and large buildups unless good ceilings and visibilities exist.

b. Flight in Other Hazardous Weather Areas.

Flight through any of the special tropical weather phenomena presents problems of turbulence and moisture similar to the ITCZ. Most of these zones offer a favorable spawning area for tropical cyclones, with the storm intensities varying greatly in short periods of time. Where these storm areas are located over warm tropical oceans, the turbulence is stronger during the evening hours.

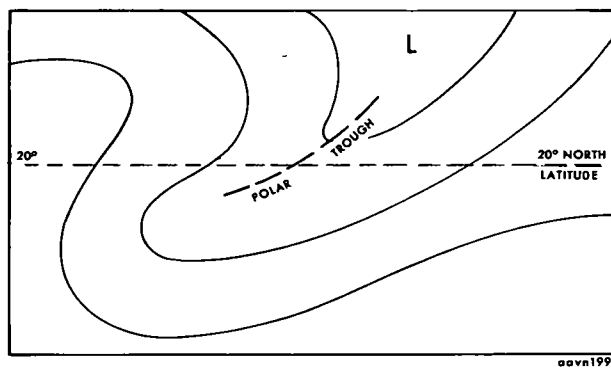


Figure C-7. The polar trough in the Tropics.

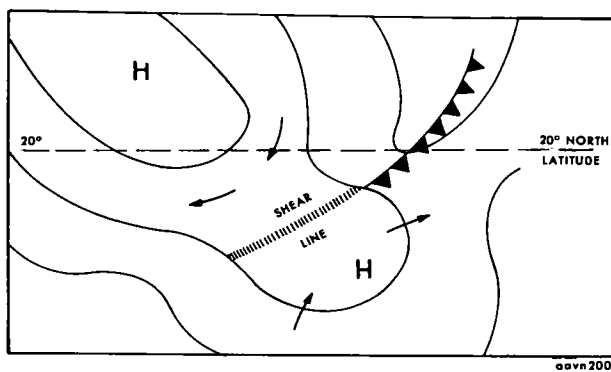


Figure C-8. Shear line in the Tropics.

GLOSSARY

The explanations and definitions contained in the glossary serve to—(1) clarify terms as used in the text; i.e., in their meteorological sense, (2) explain or define common meteorological terms not included in the text.

absolute humidity—A ratio of the quantity of water vapor present per unit volume of air, usually expressed as grams per cubic meter or grains per cubic foot. This ratio is of limited value to the meteorologist because slight changes in atmospheric pressure or temperature alter the amount of air and vapor in a specific volume, thus changing the absolute humidity even though the amount of moisture in the air (grams per kilogram) has not changed.

active front—A front which produces appreciable cloudiness and precipitation.

advection—See *convection*.

air mass analysis technique—The two primary principles to be considered in an abbreviated air mass analysis are (1) heating from below promotes instability, and (2) cooling from below promotes stability. By applying these principles in conjunction with other guidelines to a specific air mass of known moisture content, the aviator can analyze the air mass for stability, cloud type and coverage, precipitation amount and intensity, visibility restrictions, icing type and intensity, and degree of turbulence.

anemometer—An instrument for measuring the force or speed of the wind.

anticyclogenesis—A term applied to the process which creates or intensifies an anticyclone.

anvil cloud—The popular name of a heavy cumulus or cumulonimbus cloud having an anvil-like formation of cirrus clouds in its upper portions. If a thunderstorm is seen from the side, the anvil form of the cloud mass is usually noticeable.

Arctic front—The zone of discontinuity between the extremely cold air of the Arctic regions and the cool polar air of the northern Temperate Zone.

aurora—A luminous phenomenon caused by electrical discharges in the atmosphere; probably confined to the tenuous air of high altitudes. It is most commonly seen in sub-Arctic and sub-Antarctic latitudes and is called *aurora borealis* or *aurora australis* respectively, according to the hemisphere in which it occurs. Observations with the spectroscope seem to indicate that a faint "permanent aurora" is a normal feature of the sky in all parts of the world.

back—To change or shift in a counterclockwise direction (to the left of the moving mass); applied to the wind when it so changes, for example, the wind backs from the north to northwest. Opposite to *veer*, which signified a clockwise change. In scientific practice, this definition applies to both hemispheres.

blizzard—A violent, intensely cold wind laden with snow.

buildup—A cloud with considerable vertical development.

Buys-Ballot's Law—A law formulated by a Dutch meteorologist in 1857 stating—If you stand with your back to the wind, pressure is lower on your left than on your right in the Northern Hemisphere, and the reverse in the Southern Hemisphere.

calories—The amount of heat required to raise the temperature of 1 gram of water 1 degree celsius.

ceiling—The height above the earth's surface of the lowest layer of clouds of obscuration phenomena that is reported as broken, overcast, or obscured and not classified as thin or partial.

Celsius scale—A centigrade temperature scale originally based on 0° for the boiling point of water and 100° as the freezing point of water; i.e., an inverted centigrade scale. It is now used interchangeably with the centigrade scale, with 0° freezing and 100° boiling temperatures.

cloud bank—A mass of clouds, usually of considerable vertical extent, stretching across the sky on the horizon but not extending overhead.

cloudburst—A sudden and extremely heavy downpour of rain; frequent in mountainous regions where moist air encounters orographic lifting.

cold wave—A rapid and marked fall of temperature during the cold season of the year. The National Weather Service applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified minimum temperature or lower. Specifications vary for different parts of the country and for different periods of the year.

conduction—Conduction is the transfer of heat by contact. Air is a poor conductor of heat; therefore, molecular heat transfer (conduction) during the course of a day or night affects only 2 or 3 feet of air directly. Wind and turbulence, however, continuously bring fresh air into contact with the surface and distribute the warmed or cooled air throughout the atmosphere.

convection—Although frequently used in physics to denote a complete atmospheric current, in meteorology *convection* refers to vertical air motion. The horizontal air movement that completes an air current is called *advection*.

cooling processes, major—Air temperature is decreased by all or any of the following processes:

(1) *nocturnal cooling*. The earth continuously radiates its heat outward toward space. During the night (or at any time when outgoing radiation from the earth exceeds incoming solar radiation) the loss of radiant energy lowers the temperature of the earth's surface. The air temperature is thereafter reduced by conduction.

(2) *advective cooling*.

a. When the windflow is such that cold air moves into an area previously occupied by warmer air, the temperature of the air over the area is decreased. With a strong, cold wind prevailing, the advective cooling may be sufficient to cause a temperature decrease in an area even though the surface is absorbing solar radiation.

b. Warm air advection over a colder surface will result in conductive cooling of the lower air layers.

(3) *evaporative cooling*. When rain or drizzle falls from clouds, the evaporation of the water drops cools the air through which these drops are falling. Similar evaporative cooling occurs whenever liquid water is changing to vapor, thereby taking latent heat energy from the environment.

(4) *adiabatic cooling*. The process by which air cools due to decrease in pressure. If air is forced upward in the atmosphere, the resulting decrease in atmospheric pressure surrounding the rising air allows the air to expand and cool adiabatically. Weather produced by lifting processes is the result of adiabatic cooling; e.g., frontal weather, convective, and orographic thunderstorms, and upslope fog.

Coriolis force—This effect of the earth's rotation on wind direction was expressed as an acceleration by a French scientist, G.G. Coriolis, in 1844. The Coriolis acceleration becomes a force when applied to a moving mass of air, as expressed by the equation

$$C = 2\omega v \sin \theta$$

where C is Coriolis acceleration, ω is the angular velocity, and θ is the latitude where the motion occurs. The acceleration changes the wind velocity with regard to direction only.

cyclogenesis—The process which creates or intensifies a cyclone.

deepening—The decreasing of pressure in the center of a low pressure system.

density—The amount of mass per unit volume of any substance (pound per cubic foot, gram per cubic centimeter, kilogram per cubic meter, etc.) Heating

causes a substance to expand, thereby reducing the number of molecules that can be contained by a fixed volume and decreasing density. Cooling increases the density of a substance. The density of a gaseous medium is particularly sensitive to changes in temperature (and pressure). The weight of a substance varies directly with its density.

depression—A cyclonic (low pressure) area.

discontinuity—The term applied in a special sense by meteorologists to a zone within which there is a comparatively rapid and abrupt transition of the meteorological elements from one value to another.

diurnal—Actions completed within 24 hours, or pertaining to day time.

equinox—The moment, occurring twice each year, when the sun, in its apparent annual motion among the fixed stars, crosses the celestial equator; so called because then the night is equal to the day, each being 12 hours long over the whole earth. The *autumnal equinox* occurs on or about September 22, when the sun is traveling southward; the *vernal equinox* on or about March 21, when the sun is moving northward.

filling—The increasing of pressure in the center of a low pressure system; the opposite of *deepening*.

frontogenesis—The process which creates or recreates a front in areas where air mass discontinuities are intensifying.

frontolysis—The process by which a front weakens or dissipates as density of air masses change or the wind field changes.

gradient—1. The rate of increase or decrease in magnitude, such as a pressure or temperature *gradient*. When a horizontal pressure gradient exists, the direct force exerted by the area of higher pressure is called the *pressure gradient force*. 2. When used to describe a wind (*gradient wind*), gradient refers to winds above the influence of terrestrial friction—normally above 2,000 or 3,000 feet—where only pressure gradient force is affecting the speed of the wind.

gust—Rapid fluctuations in wind speed with a variation of 10 knots or more between peaks and lulls.

greenhouse effect—This term is derived from the effect of the glass roof on a greenhouse which transmits high-frequency insolation but blocks the passage of terrestrial radiation from within the glass enclosure. The greenhouse effect caused by clouds and impurities in the atmosphere is most noticeable at night when they reduce the nocturnal cooling of the earth.

horse latitudes—The subtropical high pressure region at approximately 30° latitude, characterized by calm or light, variable winds.

hot wave—A period of abnormally high temperatures, usually lasting 3 or more consecutive days

during each of which the maximum temperature is 90° F. or over.

humidity—A general term to denote the water vapor content of the air.

inclination of the wind—The angle of the wind with respect to the isobar at the point of observation (usually between 20° and 30° at the surface).

intertropical front—The boundary between the trade wind systems of the Northern and Southern Hemispheres. It appears near the Equator as a fairly broad zone of transition commonly known as the *doldrums*.

lapse rate—A change in value expressed as a ratio, generally used with temperature changes vertically; i.e., 2° C. per 1,000 feet in the standard atmosphere.

line squall—See *squall line*.

mean sea level—In the United States, the average height of the surface of the sea for all stages of the tide during a 19-year period.

mesometeorology—The study of atmospheric phenomena such as tornadoes and thunderstorms which occur between meteorological stations or beyond the range of normal observation from a single point; i.e., on a scale larger than that of *micrometeorology*, but smaller than the cyclonic (*synoptic*) scale.

micrometeorology—The study of variations in meteorological conditions over very small areas, such as hillsides, forests, river basins, or individual cities.

molecular theory—A scientific theory that all matter is composed of electrical energy organized into atoms and molecules. These molecules are in constant motion, and their collision produces temperature. The relative amount of heat energy in an object is measured by temperature scales. When radiant energy is absorbed by a molecule, the molecular energy content is increased—molecular activity speeds up and a higher temperature results. All substances which have a temperature above -273° C. also radiate energy continuously. If fresh radiant energy were not supplied by the sun, the temperature of the earth would become progressively colder.

nacreous clouds—Luminous, iridescent “clouds” occurring near 75,000 feet and made visible by reflected and diffracted light approximately 25 minutes before sunrise or after sunset; also called *mother-of-pearl clouds*.

natural air—Air as found in the atmosphere containing water vapor and other impurities.

noctilucent clouds—Silvery or bluish-white “clouds” which form approximately 55 miles above the earth and are made visible after sunset and before sunrise by reflected sunlight.

nocturnal—Occurring during the hours between sunset and sunrise.

radiation—Electromagnetic waves traveling at

186,000 miles per second, many of which may be visible as light. Cosmic rays, gamma rays, X-rays, ultraviolet rays, visible light rays, infrared rays, and radio waves are some common types of radiation which vary in wave length from 0.000000001 cm to 10,000,000,000 cm. Visible rays range from about 3.8 to 7.6 ten-millionths of a meter in wave length. The wave length emitted by an object decreases as the temperature of the object increases. A decrease in wave length signifies an increase in radiation frequency. Thus, a hot surface emits high frequency radiation. The rate at which an object emits radiation is controlled by the temperature contrast between the object and its environment. Radiation travels best through a vacuum, but the quantity absorbed by a substance is controlled by the wave frequency and the density of the absorbing medium. High frequency waves can penetrate dense media, whereas low frequency waves may be absorbed by low density media, especially by gaseous water (water vapor).

rate of evaporation—Rate of evaporation is the measured time for the changing state of a substance from a liquid to a gas. The quantity of vapor which will escape from a liquid surface into the air is primarily governed by (1) the temperature of the liquid, (2) the amount of vapor already in the air (partial vapor pressure of the air), and (3) the speed of air movement over the liquid surface. Thus, much water will evaporate from the Great Lakes into the cold, dry winter air above it, even though the air cannot support the moisture in the vapor state. The resulting condensation forms a dense evaporation fog over the lakes.

roll cloud—Part of the cloud base along the leading edge of a cumulonimbus cloud, formed by a rolling action in the wind shear region between cool downdrafts within the cloud and warm updrafts outside the cloud.

saturated adiabatic lapse rate—A rate of temperature decrease with height, equal to the rate at which an ascending body of saturated air will cool during adiabatic expansion. It varies inversely with the air temperature. The average value generally used is 1.5° C. per 1,000 feet.

secondary—A small area of low pressure on the border of a large (primary) area. The secondary may develop into a vigorous cyclone while the primary center disappears.

secondary circulation—In this wind classification category, many authorities include *only* migratory anticyclones and cyclones. Such wind patterns as land and sea breezes, mountain and valley breezes, eddies, and Foehn winds are then classified as *local winds*.

selective absorption—Substances are *selective* in the radiation frequencies which they will absorb and

radiate. The gases and impurities of which air is composed absorb and radiate only a few of their incident radiation frequencies. For example, water vapor absorbs several of the lower frequency radiation waves of terrestrial radiation, but is transparent to the high frequency radiation from the sun.

solstice—The time of year when the direct ray of the sun is farthest from the Equator. The approximate dates are—summer solstice, June 22, and winter solstice, December 22.

spread—The difference between the temperature of the air and the dew point of the air, expressed in degrees. Although there is a definite relationship between spread and relative humidity, a spread of 5° F. between 90° F. and 85° F. produces a significantly different relative humidity from the same spread between 65° F. and 60° F.

squall—A sudden increase in wind speed of at least 15 knots and sustained at 20 knots or more for at least 1 minute.

squall line—A line of thunderstorms, generally continuous across the horizon. The squall line is associated with prefrontal activity.

subsidence inversion—An inversion layer which forms near a center of high pressure where the entire column of air is descending (subsiding) toward the surface. As the air layers descend, they are compressed by the inflow of fresh air aloft. Compression heats the subsiding air layer and often the layer becomes warmer at the base levels than at the upper levels. The resulting increase in temperature through the layer is a *subsidence inversion*. Haze layers often develop below these inversion layers.

synoptic—That which presents a general view of the

whole; as a *synoptic* weather map, or a *synoptic* weather situation, wherein the major weather phenomena over a large geographical area are depicted or discussed.

temperature lag—1. Although the sun is directly overhead at noon, incoming radiation continues to exceed reradiation from the earth until after 1400 hours local standard time. Thus, the diurnal surface temperature increase reaches a maximum in the midafternoon. 2. Seasonally, the sun is highest in the Northern Hemisphere at the summer solstice (June 22), but the long hours of daylight and relatively direct incident radiation cause the summer temperatures to continue increasing into July and August.

twilight—The interval of incomplete darkness following sunset and preceding sunrise.

veer—See *back*.

weather—In addition to its complete definition (para 2-3c(1)), the term *weather* has several specialized meanings in meteorology. It may refer to (1) *only* the forms of precipitation in the atmosphere at the time of a meteorological observation, (2) *both* the forms of precipitation and the obstructions to vision (fog, haze, smoke, dust, etc.) present over a station at the time of a meteorological observation or, (3) all forms of atmospheric phenomena that affect an aircraft during takeoff, landing, and in flight.

wind shear—The rate of change of wind velocity (speed and/or direction) with distance. Eddies and gusts form in areas of wind shear, thus producing turbulent flying conditions. Wind shear may occur in either the vertical or horizontal plane.

wind velocity—The speed *and* direction of the wind.

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DEPARTMENT OF DEFENSE
USAF SKEW T, log p DIAGRAM

TEMPERATURE IN DEGREES FAHRENHEIT AND CELSIUS

SKEW T - LOG P ANALYSIS			
TIME		TIME	
AIRMASS ANALYSIS			
TYPE	BOUNDARY	FT.	FT.
TYPE	BOUNDARY	FT.	FT.
TYPE	BOUNDARY	FT.	FT.
FREEZING LEVEL(S)			
INVERSIONS			
FRONTAL			
RADIATION			
SUBSIDENCE			
TROPOPAUSE			
L.C.L.			
C.C.L.			
L.F.C.			
SIGNIFICANT WIND			
MAX.			
MIN.			
LEVELS OF SHEAR			
STABILITY INDEX			
TO		TO	
TO		TO	
TO		TO	
CLOUDS			
TYPE	AMOUNT		
BASES			
TOPS			
ICING			
TYPE			
SEVERITY			
CONTRAILS			
PERSISTENCE			
HEIGHT			
TURBULENCE			
DEGREE			
HEIGHT(S)			
MAX WIND GUSTS			
WIND SIZE			
TEMPERATURES			
MAX.			
MIN.			
CUMULUS CLOUD FORMATION AT TEMP. TIME			
DISSIPATION OF LOW LEVEL INVERSION AT. TIME			
REMARKS			
FORECASTER		FORECASTER	

EXPLANATION

ISOBARS are straight, horizontal, brown lines. The heights of the pressure surfaces in the U.S. Standard atmosphere, below the pressure values on the left, are in parentheses () for values in feet and brackets [] for meter values.

ISOTHERMS (°C) are the straight, equidistant brown lines running diagonally, upward from left to right.

DRY ADIABATS are the slightly curved brown lines that intersect the 1000 mb isobar at intervals of 2°C, and run diagonally upward from right to left. The dry adiabats for the overlap portion of the pressure range are labeled with two values. (Dry below.)

SATURATION ADIABATS are the curved green lines that intersect the 1000 mb isobar at intervals of 2°C, diverging upward and tending to become parallel to the dry adiabats.

SATURATION MIXING RATIO (in gm. per kg.) is represented by dashed green lines. The values appear between the 1000 and 500 mb lines.

THICKNESS (in hundreds of geopotential feet and meters) at the layers: 1000/700, 1000/500, 700/500, 500/300, 300/200, 200/100, 100/50, 50/10, 10/0, 0/10, 10/20, 20/30, 30/40, 40/50, 50/60, 60/70, 70/80, 80/90, 90/100, 100/110, 110/120, 120/130, 130/140, 140/150, 150/160, 160/170, 170/180, 180/190, 190/200, 200/210, 210/220, 220/230, 230/240, 240/250, 250/260, 260/270, 270/280, 280/290, 290/300, 300/310, 310/320, 320/330, 330/340, 340/350, 350/360, 360/370, 370/380, 380/390, 390/400, 400/410, 410/420, 420/430, 430/440, 440/450, 450/460, 460/470, 470/480, 480/490, 490/500, 500/510, 510/520, 520/530, 530/540, 540/550, 550/560, 560/570, 570/580, 580/590, 590/600, 600/610, 610/620, 620/630, 630/640, 640/650, 650/660, 660/670, 670/680, 680/690, 690/700, 700/710, 710/720, 720/730, 730/740, 740/750, 750/760, 760/770, 770/780, 780/790, 790/800, 800/810, 810/820, 820/830, 830/840, 840/850, 850/860, 860/870, 870/880, 880/890, 890/900, 900/910, 910/920, 920/930, 930/940, 940/950, 950/960, 960/970, 970/980, 980/990, 990/1000, 1000/1010, 1010/1020, 1020/1030, 1030/1040, 1040/1050, 1050/1060, 1060/1070, 1070/1080, 1080/1090, 1090/1100, 1100/1110, 1110/1120, 1120/1130, 1130/1140, 1140/1150, 1150/1160, 1160/1170, 1170/1180, 1180/1190, 1190/1200, 1200/1210, 1210/1220, 1220/1230, 1230/1240, 1240/1250, 1250/1260, 1260/1270, 1270/1280, 1280/1290, 1290/1300, 1300/1310, 1310/1320, 1320/1330, 1330/1340, 1340/1350, 1350/1360, 1360/1370, 1370/1380, 1380/1390, 1390/1400, 1400/1410, 1410/1420, 1420/1430, 1430/1440, 1440/1450, 1450/1460, 1460/1470, 1470/1480, 1480/1490, 1490/1500, 1500/1510, 1510/1520, 1520/1530, 1530/1540, 1540/1550, 1550/1560, 1560/1570, 1570/1580, 1580/1590, 1590/1600, 1600/1610, 1610/1620, 1620/1630, 1630/1640, 1640/1650, 1650/1660, 1660/1670, 1670/1680, 1680/1690, 1690/1700, 1700/1710, 1710/1720, 1720/1730, 1730/1740, 1740/1750, 1750/1760, 1760/1770, 1770/1780, 1780/1790, 1790/1800, 1800/1810, 1810/1820, 1820/1830, 1830/1840, 1840/1850, 1850/1860, 1860/1870, 1870/1880, 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